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The CCPDS-R Software Engineering Exercise (SEE)

G. A. Huff
S. M. Maciorowski

November 1989

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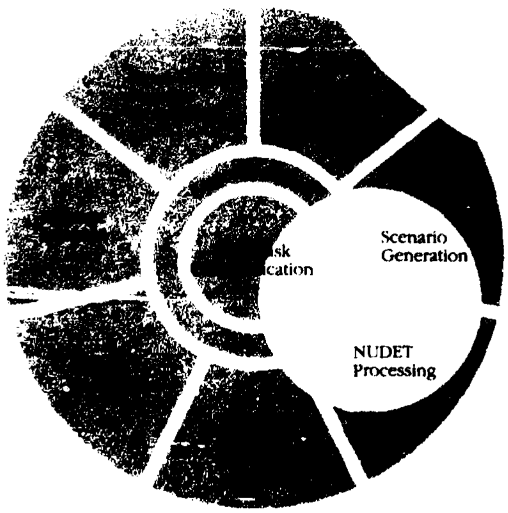

Prepared for Program Manager for CCPDS-R Program, Space and Missile Warning Systems Program Office, Electronic Systems Division, AFSC, United States Air Force, Hanscom Air Force Base, Massachusetts

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To evaluate the software engineering capabilities of potential offerors during the Command Center Processing and Display System-Replacement (CCPDS-R) Full-Scale Development/Production source selection, ESD and MITRE project personnel devised a software engineering exercise (SEE) to be carried out by all offerors. The SEE, first used on CCPDS-R, has since been utilized as a standard source selection technique by ESD and other agencies. This report describes the CCPDS-R SEE concept and provides a history of the activities and decisions made in defining and carrying out this first SEE. It documents the SEE material contained in the CCPDS-R Request for Proposal package and the SEE ground rules and problem specification issued to the CCPDS-R offerors. It also identifies lessons learned and makes recommendations for future programs which may wish to conduct a SEE.

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SECTION 1

INTRODUCTION

During the source selection for a software intensive system, an offeror is usually evaluated on his software engineering approach for managing and developing the software for the subject system. Areas of evaluation include the offeror's methodologies, tool sets, software development plan (SDP) and staffing. While evaluation of an offeror's software engineering approach during source selection gives insight into how the offeror intends to implement the software for the system, the evaluation is limited because it cannot give insight into the offeror's own expertise with the selected methodology. Frequently, the Government has assessed an offeror's software engineering approach during source selection as adequate only to discover once on contract that the offeror is not well versed in the proposed methodology and tool set or that the offeror does not follow the SDP. As a result of the offeror's lack of expertise in the selected software development approach or failure to follow a firm plan, significant cost and schedule slips are often encountered during the software development phase.

In an attempt to limit further occurrences of this situation, the Electronic Systems Division (ESD) of the Air Force Systems Command (AFSC) determined the need for a method to be used during source selection for evaluating not only an offeror's software development plan but also the offeror's expertise in the proposed software development approach. The need for this method was perceived as even greater within the next few years due to the recent Department of Defense (DOD) directives that mandated the use of Ada as an implementation language. It was feared that proposals would be submitted by offerors who were not well trained in Ada as a software engineering methodology. To resolve this situation, therefore, ESD and MITRE conceived the idea of a source selection software engineering exercise (SEE). As conceived, the purpose of the exercise was to measure the degree of risk associated with the offeror's software development approach by testing the offeror's proposed methodology, as demonstrated through the offeror's actual implementation of a small exercise system, and the offeror's ability to organize a SEE team knowledgeable in the proposed software engineering approach and Ada.

The Command Center Processing and Display System-Replacement (CCPDS-R) program was the first of five ESD programs to date to use a SEE during source selection. ESD, with technical support from The MITRE Corporation, tailored the SEE concept for CCPDS-R, determined the approach for incorporating the SEE into the source selection process, and drafted the actual exercise specification which would serve as the basis for the CCPDS-R SEE. Prior to actually using the SEE during the CCPDS-R source selection, the Government determined that the best way to finalize the SEE concept, specification and evaluation approach was for MITRE to implement the exercise itself. In that way, the Government would best be able to assess the feasibility of the SEE, including the scope of the SEE and the time that would be made available to the offerors for conducting the SEE; to ensure that the exercise specification which would be given to the offerors was well written and sufficiently challenging; and to identify meaningful criteria that would be used to evaluate the offeror's SEE results.

This report provides a history of the activities and decisions made in defining and carrying out the SEE for the CCPDS-R full scale development/production (FSD/P) phase source selection, together with a rationale for those activities and decisions, and a discussion of the Government's experiences using the SEE on CCPDS-R. In particular, it describes MITRE's dry run of the SEE as part of the source selection preparation effort, and identifies lessons learned prior to the start of the source selection. It also describes the actual execution of the SEE during the CCPDS-R source selection and the lessons learned during that period. Appendices to this report contain the CCPDS-R SEE exercise specification and ground rules provided to the CCPDS-R FSD/P offerors, as well as the SEE information included in the CCPDS-R FSD/P request for proposal (RFP) package.

1.1 CCPDS-R BACKGROUND

1.1.1 System Description

CCPDS-R will replace the current Command Center Processing and Display System (CCPDS) and the missile warning function of the NORAD Computer System. The current CCPDS is located at four command centers: Headquarters, Strategic Air Command (SAC), Cheyenne Mountain Air Force Base (CMAFB), National Military Command Center (NMCC), and the Alternate National Military Command Center (ANMCC). CCPDS is dedicated to the receipt, processing and display of ballistic missile tactical warning and attack assessment (TW/AA) information. In addition, CCPDS performs associated command center unique functions for use by the national command authorities, chairman of the Joint Chiefs of Staff, Commander-in-Chief, SAC, and Commander-in-Chief, North American Aerospace Defense Command in making decisions related to the execution of the single integrated operation plan, force/command, control and communications survival, and the use of strategic reserves during all phases of nuclear engagement.

As defined by the new integrated tactical warning and attack assessment (ITW&A) architecture, the CCPDS-R will consist of four subsystems. These are the CMAFB subsystem, the Offutt Processing and Correlation Center (OPCC) subsystem, the SAC subsystem, and the processing and display subsystem (PDS). The PDS is to be located at the CMAFB, NMCC, ANMCC, OPCC, and SAC.

The CMAFB and OPCC subsystems, referred to as the common subsystems, will have identical hardware and software. They will interface to all ballistic missile sensors via survivable and non-survivable media, process the information received from those sensors, generate displays for local consoles, integrate the missile warning information with other manually entered data on air, space, and intelligence, and have the capability for distributing this correlated information to other command centers and subscribers. The two common subsystems will process the same sensor information and serve as mutual backups in case of failure of critical components. Both subsystems will be able to distribute correlated ITW&A data to subscribers at a given time.

The SAC subsystem will be physically separate from the OPCC subsystem and will be solely devoted to the support of the SAC force management and force survival missions. It will receive data from either the OPCC or CMAFB common subsystems, from PDS, and from command-unique interfaces. It will process the data and generate displays for consoles located at the SAC command center and other locations at Offutt Air Force Base.

The PDS subsystem will be capable of receiving and displaying correlated ITW&A information from the common subsystem, direct ballistic missile sensor data, and communication systems status from the Survivable Communications Integration System (SCIS). It will be the primary system for presentation of ITW&A information at the NMCC, ANMCC, and SAC.

1.1.2 Program Description

The CCPDS-R acquisition program consists of two phases: a concept definition/design (CD/D) phase and a full-scale development/production phase. The CCPDS-R FSD/P effort is primarily a software intensive effort using Department of Defense Standard (DOD-STD) 2167 [1], Ada as the design language, and, unless a waiver is granted, Ada as the implementation language. The CCPDS-R FSD/P effort thus requires that contractors be prepared to design and develop a real-time system in Ada using modern software engineering practices. The CCPDS-R FSD/P contract was awarded in June 1987 to TRW.

The CCPDS-R CD/D phase, a year-long effort that concluded in August 1986, was primarily a study effort. The CD/D contractors were TRW and Ford Aerospace and Communications Corporation, both of which were expected to bid on the FSD/P contract. During the CD/D phase, the contractors were required to submit draft SDPs. They were also required to perform several Ada-related activities to analyze the feasibility of using Ada as the CCPDS-R implementation language and to demonstrate the contractor's capability to design and develop a system in Ada, should the contractor propose to use Ada as the implementation language. The specific Ada-related activities included:

a. Assess the feasibility of using Ada as the CCPDS-R implementation language, and evaluate current Ada programming support environments for their suitability of meeting CCPDS-R requirements

b. Devise a plan for efficient transition to Ada, if it is determined that the use of Ada is not feasible on this program at the present time

c. Define and conduct a demonstration that shows the contractor's readiness to use Ada, if it is determined that the use of Ada is feasible on this program now

d. Provide the rationale for choosing the Ada-based design language (ADL) and present an example of the ADL.

Despite the above activities, the Government determined that the CD/D contractors had not yet adequately demonstrated their ability to design and implement a real-time system in Ada using modern software engineering practices. In general, the contractors had not demonstrated an end-to-end application of their methodologies and Ada; they had only demonstrated the features of their tool sets. Therefore, since software development and Ada constitute major risks on CCPDS-R, the Government recognized the need for an additional method to better evaluate the software engineering and Ada capabilities of these two contractors and, more importantly, of any other offerors who might submit proposals for the FSD/P phase. To that end, the Government developed the software engineering exercise as part of the FSD/P source selection process.

1.2 OVERVIEW

1.2.1 SEE Objectives

The Government viewed the SEE as a practical way to assess each offeror's software engineering capability prior to FSD/P contract award. The SEE, which consists of a small system to be designed by each of the offerors, was intended to measure the degree of risk associated with the offeror's software development methodology, as documented in the offeror's software development plan. It focused specifically on the offeror's software development methodology, as demonstrated by the actual application of the methodology to the exercise system, and on the offeror's ability to organize a team for the SEE, fully knowledgeable in the proposed methodology and Ada.

Based on the offerors' performance on the SEE, the Government expected that it would be better able to evaluate the offerors' probability of success. In particular, if an offeror failed the exercise, it would be assessed that the offeror had low probability of implementing CCPDS-R within the proposed cost and schedule. If an offeror successfully completed the exercise, it would not guarantee that the offeror would be able to complete CCPDS-R successfully; however, it would provide some level of confidence in the offeror's ability to implement CCPDS-R. In either case, it would provide early identification of problem areas in the offeror's software approach, thereby enabling the Government to concentrate on these areas immediately at the start of the FSD/P phase, should the offeror be awarded the contract.

The Government did not intend to evaluate every aspect of software development via the SEE. In particular, the Government did not plan to evaluate those areas that either would not scale up to a large software development effort or would not provide meaningful or discriminating source selection information. As eventually defined, the SEE was intended to evaluate the requirements analysis and design methodologies, the actual SEE design, and the team expertise for the exercise. The SEE was not intended to evaluate coding, testing, integration, productivity, quality assurance, configuration management, software metrics, full compliance with DOD-STD-2167, schedule, and management of subcontractors. The Government elected to evaluate the offerors' proposals in these areas by following the traditional source selection evaluation approach.

1.2.2 CCPDS-R SEE System Description

For the CCPDS-R SEE to be a meaningful measure of an offeror's ability to design and develop a real-time system like CCPDS-R, the Government felt that the SEE system would have to require analysis of quantitative performance requirements and concurrent processing, like CCPDS-R, it would have to be relevant to the CCPDS-R mission, and it would have to be of suitable size and complexity so that it could be done in a reasonably short period of time. The system devised for the SEE consists of a missile-warning scenario generator and simulator. The exercise system allows the user to create and edit scenarios consisting of missile-warning events (where an event is a missile launch or nuclear detonation) and to run in real-time a missile warning simulation controlled by a selected scenario. The exercise system also allows the user to be able to run a particular scenario simulation while editing that same scenario file. This requirement forces the offerors to address real-time, concurrent operations comparable to those found in CCPDS-R. Appendix A contains the CCPDS-R SEE system specification as provided to thr offerors.

1.3 SCOPE

This report summarizes the Government's efforts on the software engineering exercise both in preparation for and during the CCPDS-R FSD/P source selection. Sections 2 through 4 address Government SEE efforts prior to the start of the CCPDS-R FSD/P source selection. In particular, section 2 addresses MITRE's own approach for dry running the SEE, section 3 describes the plans devised by the Government for evaluating the offerors' SEE results during source selection, and section 4 summarizes the lessons learned from the MITRE dry run of the SEE. Sections 5 through 7 describe the actual execution of the SEE during the CCPDS-R FSD/P source selection. Section 5 summarizes the actual source selection conduct of the SEE, including the process of issuing the SEE to the offerors, the SEE products received from the offerors, and the Government's approach to evaluation of the offeror's SEE products. Section 6 describes the lessons learned from administering the SEE during source selection, and section 7 summarizes the offerors' feedback concerning the use of the SEE. Finally, section 8 provides an overall summary of conclusions and recommendations reached both prior to conducting the SEE during the CCPDS-R FSD/P source selection and as a result of using the SEE in the CCPDS-R FSD/P source selection.

SECTION 2

MITRE DRY RUN

Once the Government devised the SEE concept and completed the SEE requirements definition and preliminary SEE system specification (also referred to as the exercise specification), but prior to giving the SEE to the offerors, MITRE assembled a team to dry run the SEE. The primary objectives of the dry run were to generate a clearly defined SEE system specification, to develop the ground rules for the offerors to follow when conducting the SEE, to identify a set of discriminating SEE source selection evaluation criteria, and to assess whether the SEE could reasonably be done in the time allotted to the offerors. The secondary objectives of the effort were to further educate CCPDS-R staff in requirements analysis and design methodologies, ADL, and Ada, and to gain familiarity with DOD-STD-2167, a new software development standard for DOD acquisitions.

This section describes the MITRE dry run of the SEE. In particular, it discusses the makeup of the MITRE SEE team; the tools, techniques, and methodologies selected for carrying out the implementation, and the approaches taken for educating team members in them; the schedule; the activities that occurred during requirements analysis; the activities that occurred during the design phase; an overview of the resulting SEE design; and the source selection documentation that was produced for the SEE using the results of the dry run.

2.1 SEE TEAM

The MITRE SEE team consisted of eight people with assigned roles. The particular roles, along with the planned percentage of total time to be devoted to the SEE, are as shown below.

Role	Number of Individuals	Percentage of Time
User/"Government" Representative	1	30
Software Development Manager	1	30
Technical Lead	2	80, 50
Ada Consultant	1	5
Designer	2	80, 60
Designer/Recorder	1	80

All team members had in common a computer software background and knowledge of either PASCAL or similar higher order languages. Only two team members could be considered both software engineering/Ada experts with extensive experience. Two other team members had considerable Ada experience, while the remaining team members had little or no actual Ada experience. At the start of the dry run, the team had no software development methodology or tool set in place.

2.2 SELECTED TOOLS AND METHODOLOGIES

To overcome its lack of a predetermined software development methodology and environment, the SEE team selected a number of tools and methodologies for dry running the SEE, and then undertook efforts to become educated in them. The particular tools and methodologies selected were as follows:

a. The team elected to develop the exercise system in accordance with DOD-STD-2167, as tailored for the CCPDS-R program [2], and using Ada as the design language, since the offerors would be required to do this.

b. For a design methodology, the team selected object-oriented design (OOD) as defined by Grady Booch in "Software Engineering with Ada" [3]. Booch's version of OOD was selected because it was one of the better known and documented methodologies, several of the team members were acquainted with it, and it was expected that potential CCPDS-R FSD/P offerors might propose a similar methodology.

c. For a software development environment, the team chose the VAX/VMS Ada environment since it was readily accessible via the MITRE Bedford Computer Center, most team members were familiar with it, and it provided sufficient capabilities to meet the demands of the exercise.

d. As a graphical design representation technique, the team selected Buhr diagrams as defined in "System Design With Ada" [4] because the technique is designed for use with Ada, it is compatible with Booch's OOD, and it provided a more extensive mapping from Ada and design constructs than did Booch's notation.

e. For the Ada-based design language, the team chose a draft ADL standard that had been developed for another ESD project. A number of team members were acquainted with it.

f. The team did not select any particular methodology for requirements analysis, primarily because the team initially felt that the exercise was relatively small, all members understood the requirements clearly, and no data flow/data dictionary tools were readily available.

To become educated in all of these selected tools and procedures, the team studied numerous articles, participated in group discussions, and conducted demonstrations under the tutelage of the technical leads and consultant. The total time allocated throughout the effort for education in the tools and methodologies was minimal, estimated at approximately five days distributed over a 2-week period.

2.3 SCHEDULE

Prior to commencing the actual design and development of the SEE, the team technical leads developed a schedule and work plan for the effort. Figure 1 depicts this initial projected schedule. This schedule, though longer than that anticipated for the CCPDS-R offerors, was considered justifiable since the team required training in the methodology, which the offerors should not; the team members were not dedicated full time, as the offerors' members were expected to be; and the team needed to prepare additional documentation not required of the offerors. As figure 1 reveals, the projected effort

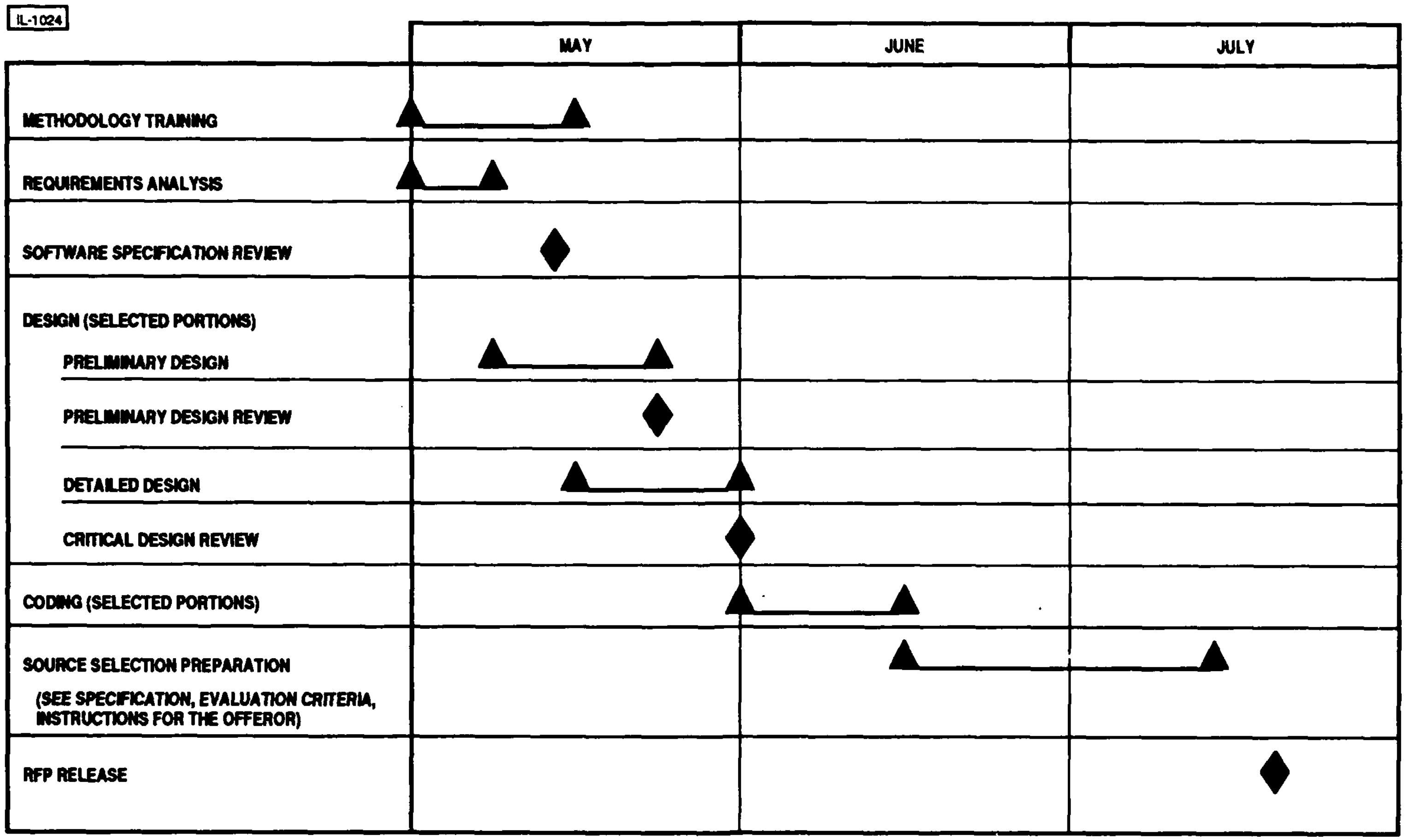


Figure 1. Projected MITRE SEE Dry-Run Schedule

would extend over a 2 1/2 month period, with 1 week allocated for requirements analysis, 3 1/2 weeks for design, 1 1/2 weeks for coding of selected portions, and 2 1/2 weeks for developing the source selection documentation (e.g., final exercise specification, evaluation criteria, etc.). This initial schedule represented an accelerated effort based on an anticipated 15 July 1986 release of the CCPDS-R RFP package. The actual schedule followed for the SEE dry run, however, turned out to be considerably longer. Figure 2 depicts the actual MITRE SEE dry run schedule. The primary reasons why the team deviated from the original schedule were that team members were unable to devote as much time as originally planned, particular efforts, such as requirements analysis, took much longer than estimated (see section 4.1.2), and unrelated delays occurred in the CCPDS-R RFP release which obviated the need for the original, accelerated schedule.

2.4 REQUIREMENTS ANALYSIS ACTIVITIES

The team commenced its dry run of the SEE by conducting an analysis of the SEE specification requirements. Input to this requirements analysis effort was the draft SEE system specification described in section 1.2.2. The team assumed at the start of the requirements analysis phase that the draft exercise specification was essentially free of major ambiguities and inconsistencies. This assumption was based on a quick reading of the draft specification and the feeling of the team that such a short specification probably did not have any serious problems in it. The team's main objectives for this phase were to define a software architecture that clearly identified the computer software configuration items (CSCIs) for the exercise system, to create adequately detailed software requirements specifications (SRSs) that provided the technically important portions of the DOD-STD-2167 data item (DI) description (DID), such as the definition of inter-CSCI interfaces, and to identify any ambiguities remaining in the exercise specification.

The team's first step in the requirements analysis effort was the development of an overall software architecture for the exercise system. The software architecture which the team developed consisted of four CSCIs: two application-level CSCIs, the missile warning simulator (MWS) and the scenario generator (SG); a user-system interface (USI) CSCI; and a file manager (FM) CSCI. Figure 3 uses Buhr notation to depict the major components of this architecture and the control and data flows among them. As figure 3 reveals, there are two major, independent control threads that tie the system together: the first passes from USI through SG to FM, and the second passes from USI through the MWS to FM. In the absence of other guidelines, the team decided to allocate particular requirements to each CSCI so as to reflect most accurately and straightforwardly the requirements breakdown in the draft exercise specification. Also, the team decided to decompose the system into these four distinct CSCIs rather than one CSCI with four computer software components (CSCs) for two primary reasons: first, the team wanted to make the design non-trivial so that the team would be forced to deal immediately with issues of interface definition and performance allocation; and second, the team wished to view the exercise specification as if it was a real specification that required a high level decomposition and the creation of at least two SRSs.

Upon development of the overall software architecture for the exercise system, the SEE team carried out a number of other activities and generated specific products. The specific activities conducted and products generated during the requirements analysis phase included

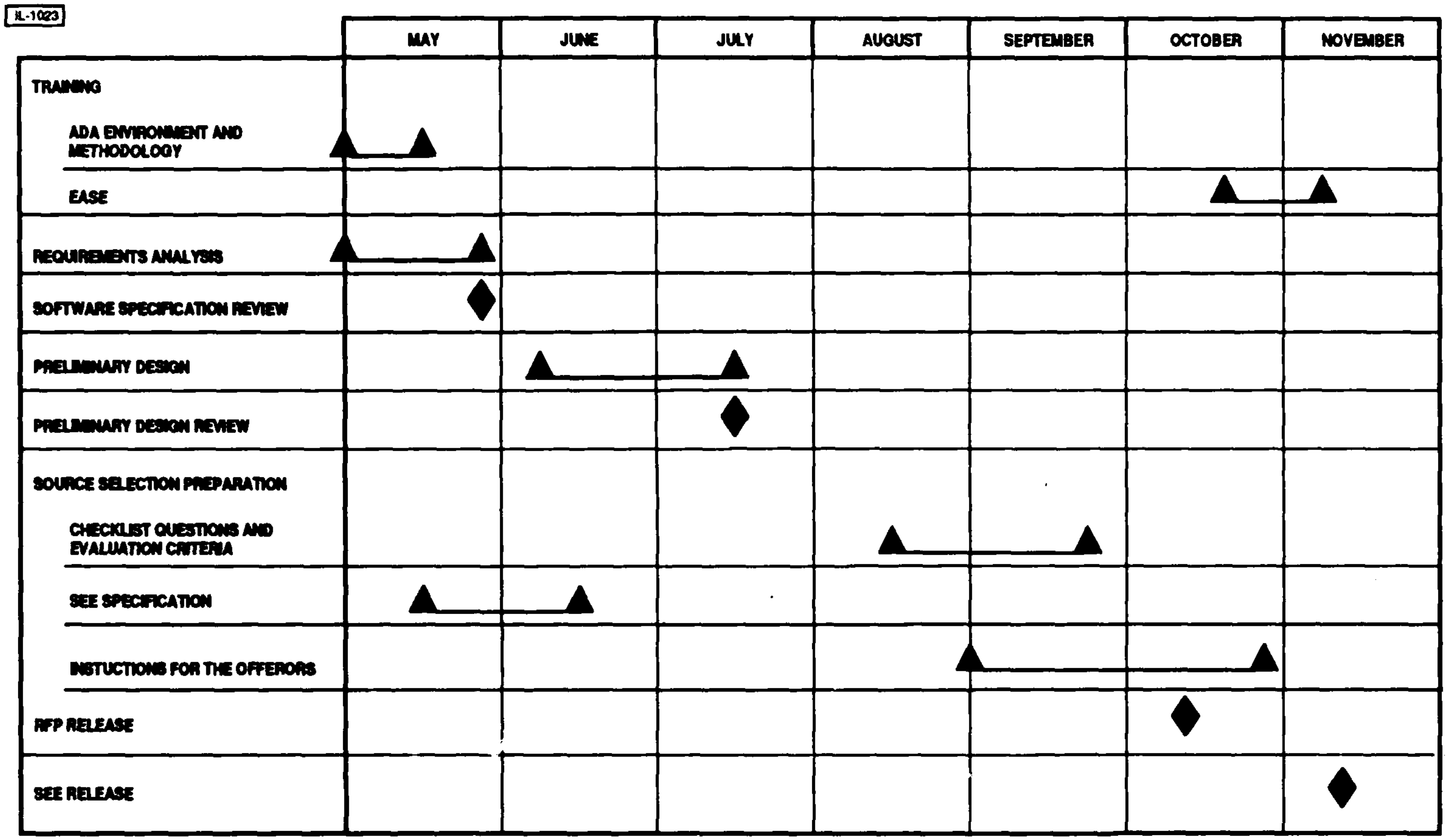


Figure 2. Actual MITRE SEE Dry-Run Schedule

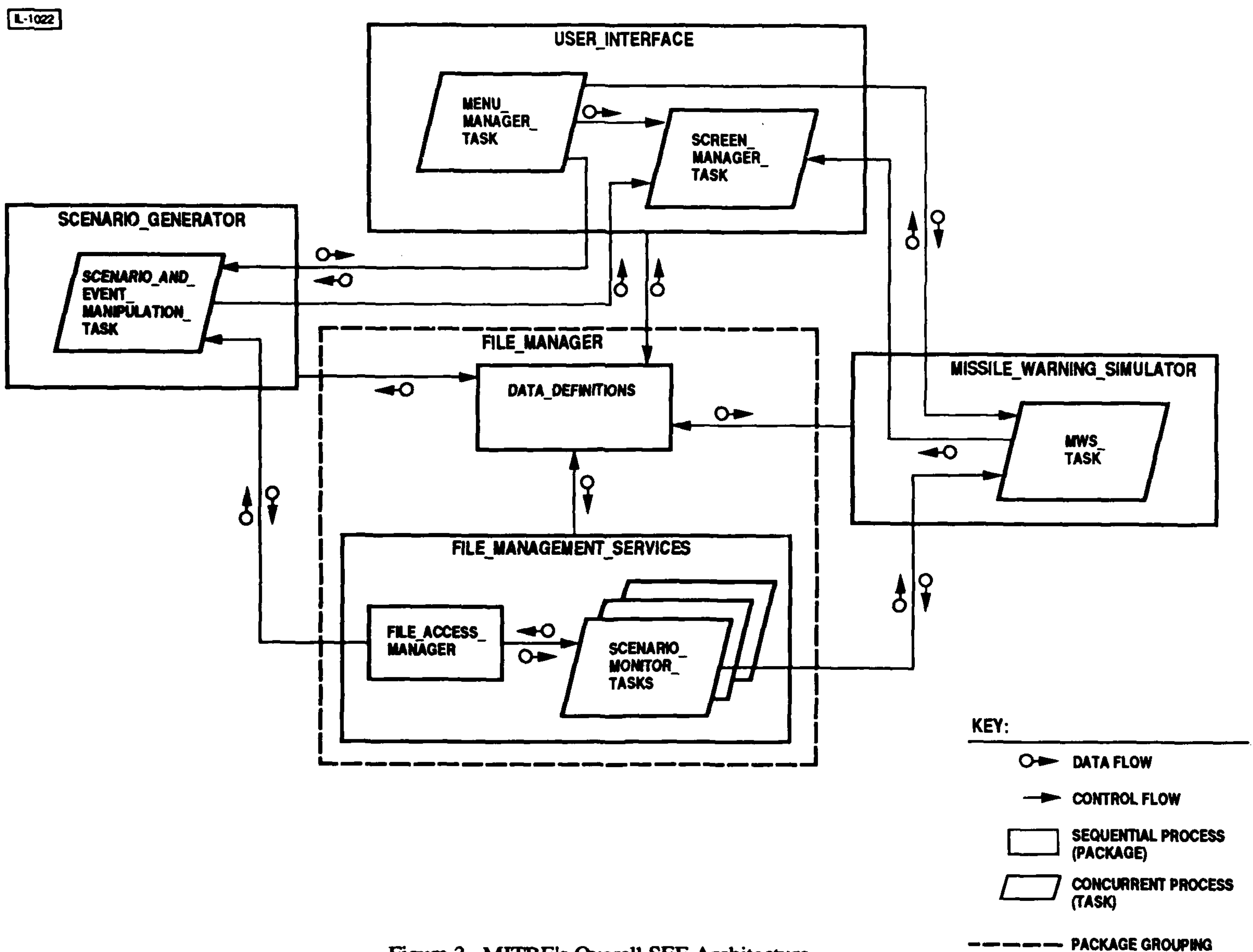


Figure 3. MITRE's Overall SEE Architecture

a. Documentation for most SRS sections for all four CSCIs. Sections of the SRSs not prepared included adaptation requirements, qualification requirements, and quality factors. These sections were not generated either because the team did not have sufficient time to prepare them, the team did not expect the offerors to complete these sections in their allotted time to conduct the SEE, or the sections did not provide any elaboration of requirements contained in the exercise specification.

b. A partial allocation of timing budgets to CSCIs. A complete allocation was not performed because there was insufficient time to finish this task properly and because the team did not have control over the target execution environment (a time-shared VAX).

c. Interface specifications for each CSCI-to-CSCI interface.

d. Data flow diagrams for selected functions and a global data dictionary.

e. A "mock" software specification review (SSR) in accordance with DOD-STD-2167.

f. A revised draft of the system specification that reflected the discussions held during the definition of the CSCIs and their interfaces (see section 2.7.1).

Although the team did not apply a formal requirements analysis methodology, the use of a data dictionary and data flow diagrams was sufficient for the team to complete the other efforts identified above, to develop the overall software architecture, and hence, to achieve all of the requirements analysis phase objectives. The team did feel that a more comprehensive exercise than the one defined would have forced the use of a formal methodology.

2.5 DESIGN ACTIVITIES

The SEE team started the design phase of the dry run upon completion of the mock SSR and review of the draft SRS documents. The team's objective for this phase was to raise as many Ada-related methodology and design issues as possible. It was not the team's objective to develop a complete, fully documented design. The team selected two of the CSCIs, scenario generator and file manager, for which to conduct preliminary design. The team picked these two CSCIs for four reasons: first, these CSCIs shared a non-trivial interface that required the joint, consistent specification of data elements, control flow, and timing budgets; second, these CSCIs formed a portion of one of the two major independent control threads in the exercise system; third, the correct operation of the file manager required that the preliminary design show evidence that certain concurrent read/write issues had been resolved; and fourth, of the SRS documents prepared by the team, the SRSs for these CSCIs were the most detailed.

As stated in section 2.2, the team carried out preliminary design for the two selected CSCIs using Booch's OOD methodology. In addition, the team developed Buhr diagrams and ADL for the SG and FM CSCIs. Figure 4 is a sample of one of the Buhr diagrams produced for a file manager function, Retrieve_Event. The team did not develop formal software top-level design documents (STLDDs) for these CSCIs, due to lack of time; however, the team made most of the technical decisions needed for these documents and presented the results at a mock preliminary design review (PDR). The team did no further design work following the mock PDR, the reasons being that team members could

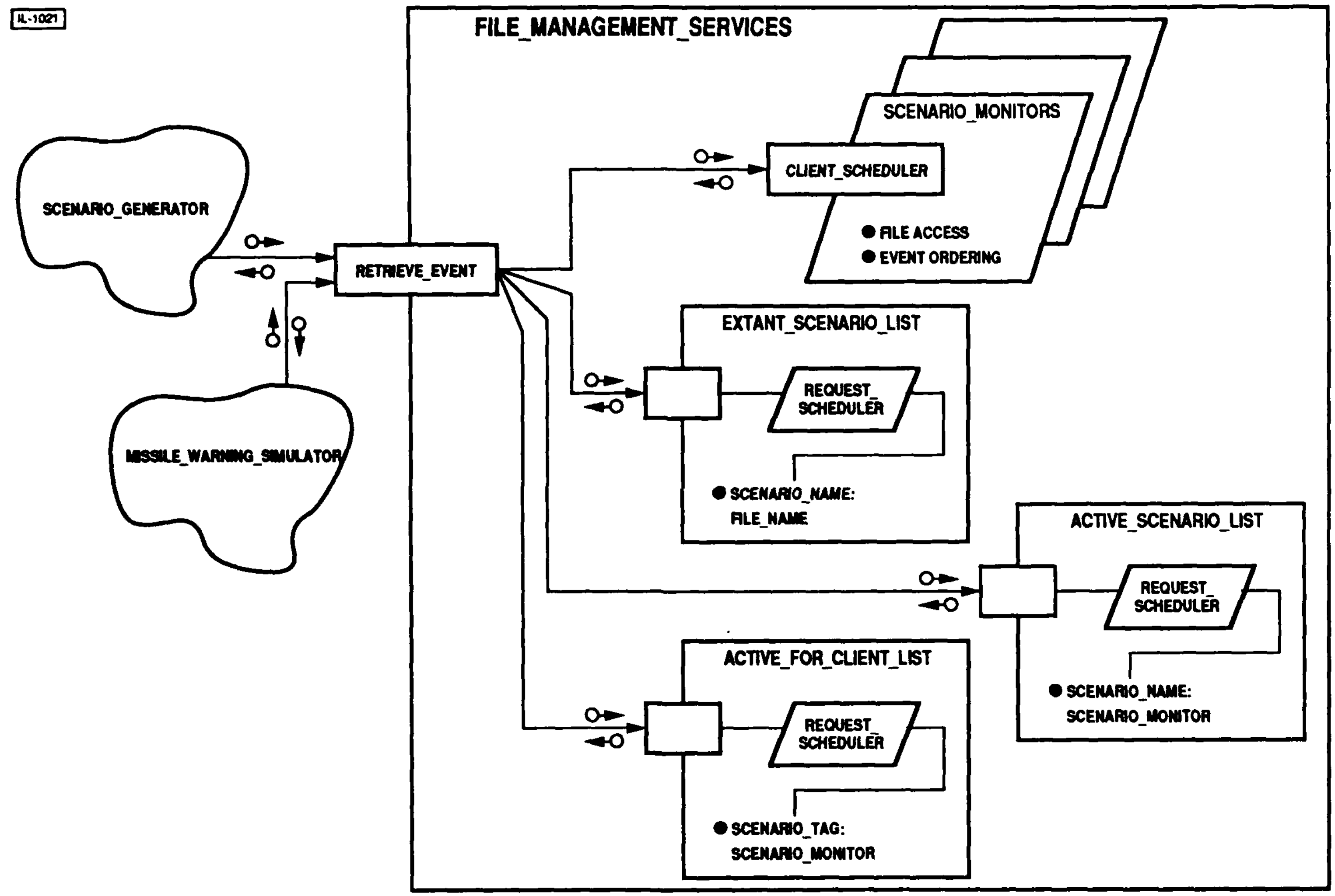


Figure 4. Sample Buhr Diagram: RETRIEVE_EVENT

no longer devote large amounts of time to the dry run and members felt that no additional discriminating design issues would be raised by continued design decomposition.

At the conclusion of the design phase, the team identified a number of Ada-related methodology and design issues which were encountered during the dry run. The most prominent methodology issue was the transition to preliminary design from requirements analysis, following the guidelines in Booch's OOD methodology, and in particular, the introduction of ADL. The most important design issue was related to the Ada tasking model: the prioritization of tasks and the avoidance of deadlock, race conditions, and task starvation. A second important issue concerned the treatment of system initialization and termination, and their interrelation with the Ada elaboration rules. With the identification of these and other issues (see section 4 for a discussion of these issues), the team satisfied its design-phase dry-run objective.

2.6 RESULTING SEE DESIGN

At the completion of the design-phase dry run, the design for the SEE system which emerged consisted of a menu-driven system containing four CSCIs, each running asynchronously. In the design, USI is an Ada task which generates the menus used to solicit input commands from the user; validates all user inputs; forwards valid scenario generator and missile warning simulator commands for processing to SG and MWS, respectively; accepts data from SG and MWS, and generates appropriate menus to solicit input commands or missile warning displays. SG is an Ada task that performs scenario generation processing, allowing the user to create, edit, delete and save scenario files consisting of missile launch and nuclear detonation message events. MWS is an Ada task that performs the simulation processing for a particular scenario file; that is to say, it performs processing on the event messages in the simulation scenario, calculates missile warning display information elements based on the contents of the event messages, and makes the information elements available for display by USI. Finally, FM is an Ada task that provides a common set of mechanisms for SG and MWS to access a centralized database of scenario files and to prioritize requests by SG and MWS for access to the scenario files.

2.7 SEE DOCUMENTATION

As stated in section 2, two of the primary objectives of the MITRE SEE dry run were to generate a clearly defined SEE system specification and to develop the ground rules for the offerors to follow when conducting the SEE. The Government considered these products essential to scope the exercise, to achieve a meaningful exercise, and to ensure commonality among offeror approaches and efforts (e.g., what hardware could be used and what products were to be generated by the offerors as part of the exercise), thereby enabling the Government to evaluate the offerors' SEE results in an objective and consistent manner. The actual SEE system specification and ground rules, or detailed instructions for the offeror, which were generated upon completion of the dry run of the SEE are contained in appendix A. A description of these documents and their derivation is contained below.

2.7.1 SEE Specification

MITRE commenced the SEE dry run using a draft SEE system specification. At the completion of the dry run, when determining whether to modify this specification in certain areas, an issue was raised as to the appropriate level of detail for the specification; some team members wanted very detailed requirements in the specification, and some felt that very detailed requirements were inappropriate since they implied design. The resolution for this dilemma was to incorporate the very detailed requirements into the specification only if they were necessary to bound the scope of the exercise; otherwise, the detailed requirements were omitted and left as a design issue for the offerors. Thus, the major modifications the team made to the draft specification as a result of the dry run concerned the areas of hardware, growth and flexibility, and performance requirements.

2.7.1.1 Hardware

The draft SEE system specification stated only that no special hardware was needed for the exercise system. The team modified the SEE specification, however, to require that no special graphics hardware or capabilities be used and that the user interface be designed to operate on a single dumb terminal with keyboard entry device. The team made these changes to ensure a level of commonality among the offerors' designs and to preclude the offerors from focusing their efforts on sophisticated graphics capabilities at the expense of addressing key software design issues.

2.7.1.2 Growth and Flexibility

Initially, the SEE system specification had no requirements for growth and flexibility of the exercise system. Since growth and flexibility are key requirements of the CCPDS-R system, the team elected to add requirements to the SEE specification in these areas so that the offerors could be evaluated on their approaches for handling growth and flexibility. In particular, the team added both a general and a detailed set of growth and flexibility requirements. The general requirement specified that the design be modular to facilitate changes in software components which are needed to accommodate future changes in operational requirements. The detailed requirements specified that the system include the capability for the user to query an individual scenario file based on a fixed set of criteria, and that the system be flexible enough to allow as future growth the capability for the user to query across multiple scenario files for this same set of fixed criteria.

2.7.1.3 Performance Requirements

The draft exercise specification contained no performance requirements. Again, since performance is a key requirement of the CCPDS-R system, the team decided to add detailed performance requirements and load conditions to the SEE specification so that the offerors could be evaluated on their approaches for addressing performance issues. As part of this approach, the team included in the SEE specification some exact performance requirements from the CCPDS-R system specification [2]. The team also left some of the SEE performance requirements ambiguous. For example, some of the SEE requirements were unclear as to the end points for measuring performance. This approach of leaving ambiguous requirements in the specification provided the Government the opportunity to evaluate the offerors' methodologies for their ability to handle one of the key functions of requirements analysis, namely, the detection and resolution of specification ambiguities.

2.7.2 Instructions for the Offeror

In addition to the SEE system specification, at the completion of the SEE dry run, the SEE team generated a detailed set of offeror instructions. The major ground rules included in the detailed instructions for the offeror (see appendix A) pertained to the exercise scope and duration, Government interaction, the offeror's methodologies and tools, team composition, and deliverable products and their formats.

2.7.2.1 Exercise Scope and Duration

Based on the results of the dry run of the SEE, the team reached the following conclusions regarding the scope and duration of the exercise:

a. A complete implementation of the exercise system, from requirements analysis through coding and testing, could not be done within the time period allocated during the CCPDS-R source selection.

b. Coding and testing of the exercise system would not provide significant discriminating information regarding one's ability to design and implement a real-time system in Ada. Use of Ada as a design language during the preliminary and detailed design phases provided sufficient information to assess one's ability in these areas.

c. Allowing the exercise period to exceed four weeks was not considered beneficial. Comparable to a college "take home" examination which has a point at which no further improvement in quality is achieved, it was determined that no further discriminatory information could be obtained by allowing the exercise period to extend beyond four weeks to six or eight weeks, for example. In fact, having the exercise go beyond four weeks could be detrimental since it could result in an overload of SEE material for the Government to evaluate.

Given the above conclusions, the team specified in the detailed instructions for the offerors that the offerors develop a complete software architecture for the exercise system; conduct requirements analysis and preliminary design for two or more components of that architecture, with the components to be selected by the offeror; and conduct detailed design for one or more components of the architecture, again with the components selected by the offeror. This would provide the Government with sample products from each major software development phase with minimal burden on the offeror. Also, the team specified that the exercise duration, from offeror receipt of the SEE specification and ground rules until delivery of the completed products, be limited to 3 1/2 weeks.

2.7.2.2 Government Interaction

The MITRE dry run of the SEE was conducted in accordance with DOD-STD-2167, as tailored for CCPDS-R [2]. As such, it included some of the typical reviews held during the software development effort, such as the software specification review and preliminary design review. During these reviews, participating personnel assumed the roles of Government acquisition agencies, Government using agencies, and contractors. Conducting these reviews provided the "contractors" the opportunity to submit questions to the "Government" to obtain clarification of requirements, resolution of specification ambiguities, and design verification. During the conduct of these reviews, it became evident that CCPDS-R offerors might develop similar questions during their implementation of the SEE which would require resolution. In the interest of fairness, it was considered undesirable to have any interaction between the Government and the offerors during the exercise period, since one offeror might inadvertently be given more information or direction than another. Therefore, in the recommended instructions for the offeror, the team explicitly stated that there would be no interaction between the offerors and the Government during the offerors' execution of the exercise. Should the offerors have any questions on the exercise, the offerors were instructed to identify appropriate assumptions, to document those assumptions, and to proceed with the exercise based on those assumptions.

2.7.2.3 Methodologies and Tools

During the dry run of the SEE, the observation was made that while a particular methodology may be considered complete and satisfactory in theory, it may turn out to require modification once it is actually used on a real application. This was considered true for the object-oriented design methodology used by the SEE team (see section 4.2). The instructions for the offeror specified that all offerors must follow their proposed requirements analysis and design methodologies as documented in the SDPs submitted with the CCPDS-R technical proposal; however, the offerors were also allowed to submit with their delivered SEE products changes to their SDPs which provided further concise, technical detaiis regarding the methodologies used during the SEE requirements analysis and design phases. These changes would be considered part of the offeror's technical proposal and subject to Government evaluation.

The observation was also made that familiarity with the selected tool set was essential in order to promote ease of design and development. The fact that a number of the team members were not well versed in the selected VAX Ada environment and tool set slowed progress. However, to require that the CCPDS-R offerors use the actual tool sets proposed CCPDS-R did not appear suitable since the offerors might not have all the tools in house. (It was not considered proper for the Government to mandate that offerors expend funds to obtain these tools for the SEE.) Consequently, in the recommended instructions for the offeror, the team specified only that the offerors use the tool set proposed for CCPDS-R to the maximum extent practical, as this would be viewed more favorably by the Government.

2.7.2.4 Team Composition

During the course of the SEE dry run, it became evident that to develop the system correctly and with ease, each team member needed to be well versed in the selected methodology and tool set, as appropriate for the member's role on the team. It also became evident that outside consultants with very strong skills in these areas could easily be brought in to carry out the exercise, thereby circumventing the intent of having specific offeror personnel conduct the exercise. Consequently, in the suggested instructions for the offeror, the team specified that offeror participation in the exercise be limited to those key individuals identified in the offeror's technical proposal as part of the CCPDS-R FSD/P team, that subcontractors who will be responsible for software development on CCPDS-R be active participants, and that consultants be precluded from participating. To verify offeror compliance with these ground rules and to assess the knowledge of individual offeror personnel in the methodology, the team further specified that, after submission of the SEE products, the offerors present a briefing to the Government on their SEE results, at which time the Government would be able to question all offeror team members on their role in the exercise and on specific technical aspects of the submitted design, methodology and tool set. Responses to these Government questions would be considered part of the offeror's SEE products, and subject to evaluation by the Government.

2.7.2.5 Deliverable Products

During the course of the SEE dry run, the question arose as to what materials the offerors should submit for evaluation and in what format the products should be delivered. The team concluded that, for those software architecture components the offerors chose to analyze and design, the offerors should submit all requirements analysis and design products, both textual and graphical, that they generated as part of their methodology and which are required per DOD-STD-2167, as tailored for CCPDS-R. These products included, for example, SRSs, STLDDs, software detailed design documents (SDDDs), and performance analyses. Also, the team concluded that the offerors should submit all textual products of the exercise, including requirements analysis conclusions and documentation, ADL listings, and other design documentation both in hardcopy form and in machine-readable, 9-track tape. The tape format provided the Government the capability to browse through the text, to apply certain design analysis tools to the ADL, and to verify that the offerors' ADL was compilable. Finally, the team concluded that the offerors should present a briefing to the Government on their SEE results. This briefing would take place following initial Government evaluation of the SEE products and would enable the Government to verify its rating of the offerors' SEE performance and to assess the knowledge of the offerors' team members, as described in section 2.7.2.4. The instructions for the offeror were written to include these specific directions.

SECTION 3

PLANS FOR EVALUATING THE OFFERORS

To evaluate the offerors' performance on the SEE, the MITRE SEE team developed a set of evaluation criteria based on a set of possible discriminating issues found during the dry run of the SEE. This section presents a general overview of source selection evaluation terminology. It then describes the source selection approach chosen for the SEE and delineates how these discriminators were used to derive a set of objective source selection evaluation criteria. Next, this section presents a description of some tools and techniques selected to assist the Government in evaluating the offerors' SEE products. Finally, this section details how the Government presented the SEE to the offerors and how the Government planned to evaluate the offerors' products.

3.1 SOURCE SELECTION TERMINOLOGY OVERVIEW

As defined in Air Force Regulation (AFR) 70-15, "Source Selection Policy and Procedures" [5] and Electronic Systems Division supplement 1 to AFR 70-15 [6], during source selection, offerors' proposals are evaluated against a set of predefined criteria. The evaluation criteria are correlated to important aspects of the program which are significant to the selection decision and particularly to aspects of the program that constitute high risk. The evaluation criteria are arranged as evaluation areas which are broken down further into items, which in turn may be broken down into evaluation factors and possibly subfactors. The evaluation criteria and order of importance are described to the prospective offerors in section M of the RFP; however, normally the evaluation factors and subfactors are not identified in the RFP, section M.

During source selection, offerors' proposals are rated against the evaluation criteria using predefined standards and scoring methods. At the lowest applicable evaluation criteria category (e.g., item, factor, subfactor), standards are prepared and used as positive indicators of the minimum performance or compliance acceptable to enable an offeror to meet the requirements of that evaluation criteria. Thus, standards are the measures by which the Government scores an offeror's proposal as acceptable or unacceptable.

3.2 SEE SOURCE SELECTION APPROACH

3.2.1 SEE Evaluation Criteria

Based on the dry run, the team determined that the critical issues for evaluating the CCPDS-R FSD/P SEE products were the robustness and cohesion of the offeror's requirements analysis, preliminary design, and detailed design methodologies; the offeror's familiarity with the methodologies and tools; the offeror's Ada/software engineering expertise; the robustness, cohesion, and completeness of the submitted exercise design; the offeror's ability to address and analyze real-time requirements and issues; the offeror's clarity and communication of design, including the use of ADL to express design; and the offeror's compliance with the SEE system specification and the offeror's own SDP. The team assessed that an evaluation of these issues as reflected in the offeror's SEE products would provide sufficient evidence as to the offeror's ability to design and develop a real-time system in Ada using modern software engineering practices. Any other issues such as coding, metrics, and full compliance with DOD-STD-2167 were considered unnecessary. Thus, the Government included only the above high-level evaluation criteria for the SEE in section M of the CCPDS-R RFP.

Given this high-level criteria, the Government identified where the SEE should be included in the CCPDS-R FSD/P source selection process. Since the CCPDS-R source selection approach included only two evaluation areas, technical and cost, the Government determined that the SEE be included as one of the four items, of equal importance, in the technical area. The Government felt that the SEE should not be incorporated under the source selection general considerations area, since this area carries less weight than the evaluation areas. Also, the Government concluded that the SEE item should be decomposed into three factors and associated subfactors as follows:

a. Factor: methodologies
   1. Subfactor: requirements analysis methodology
   2. Subfactor: design methodology
   3. Subfactor: interrelationship between requirements analysis and design methodology

b. Factor: design

c. Factor: team expertise
   1. Subfactor: methodologies
   2. Subfactor: team composition

Since these factors and subfactors only reflected a consolidation and reorganization of the SEE criteria already contained in the RFP, section M, the Government elected not to include these factors and subfactors in the section M provided to the prospective offerors [2].

3.2.2 SEE Scoring Method

During the dry run of the SEE, it became evident to the team that an offeror's failure to follow a stated software engineering approach could not be corrected via revision during the source selection period. Thus, for source selection the Government decided to give the offerors only one opportunity to carry out the SEE. The Government instructions stated that offeror revisions or changes to SEE products accomplished after the conclusion of the SEE period would not be evaluated. Further, rather than use the typical color coding and risk-scoring approach documented in AFR 70-15, which allows the offerors to submit proposal revisions in response to Government clarification requests and deficiency reports, the Government decided that a unique scoring approach be used for the SEE in which no clarification requests or deficiency reports were employed. The scoring method defined for the SEE was strictly pass/fail with no risk designated. With this approach, an offeror was assessed a rating of pass for the SEE item if the offeror's SEE proposal was judged outstanding or satisfactory in two of the three SEE factors; otherwise the offeror was assessed a rating of fail. Each of these three SEE factors was rated as outstanding, satisfactory, or unsatisfactory. Outstanding indicated that the offeror exceeded minimum requirements in a beneficial way with no significant weaknesses. Satisfactory indicated that the offeror met minimum requirements with some weaknesses that could be controlled. Unsatisfactory denoted that the offeror failed to meet the minimum requirements;

weaknesses could not be readily or reasonably corrected. With this approach, a rating of fail for the SEE did not render an offeror automatically ineligible for award.

3.2.3 Discriminator Issues

Prior to the commencement of the CCPDS-R source selection technical evaluation, the MITRE SEE team developed preliminary standards for each of the above SEE factors and subfactors based in part on the recommended evaluation criteria and a set of lower level discriminating issues identified during the course of the SEE dry run. The lower level discriminators related to identification of specification ambiguities, allocation of timing requirements across system components, behavioral aspects of the exercise system, interface specification, and consistent representation of design information across ADL, text and graphics.

3.2.3.1 Specification Ambiguities

In the dry run of the exercise, the team discovered instances of incompleteness and ambiguities in the draft exercise specification. Many of these instances were uncovered during requirements analysis only after discussion among the team members; initially, each member thought he or she understood the intent of the requirements and only when two members had to agree did the incompleteness become apparent. Many of these ambiguities were impossible to resolve fully until derived requirements were presented at the SRS level. An example is the interpretation of the requirement that the exercise system will "simulate the CCPDS-R missile warning capability in real-time" (see appendix A). Other areas of incompleteness related to the difficulty of stating performance requirements concisely; for example, the requirement that the "time from completion of [data] entry [by the user] until the database is modified to reflect the update shall not exceed two seconds" (see appendix A). Such requirements force end-to-end performance measurement across different components. To prevent incorrect interpretations of specification ambiguities from having later catastrophic and costly results, it is imperative that the methodology employed for requirements analysis include approaches for detecting and resolving specification ambiguities and inconsistencies. The offerors' SEE products were therefore expected to reflect a thorough identification and resolution of specification ambiguities.

3.2.3.2 Timing Requirements

As a result of the dry run, the team found that allocation of timing budgets to software components for the SEE was very difficult to support analytically. As mentioned above, this was due in part to inherent problems in stating quantitative performance requirements in a rigorous, testable manner. But the primary problem was due to the nature of the exercise: the analysis to support timing budget allocation requires simulation and/or prototyping activities, and the tools and time needed to do this were not available to the team during the exercise period. The team also found that timing analyses must be done during the requirements analysis phase to do a proper allocation of requirements. The offerors' SEE results were therefore expected to include an explicit performance analysis activity, done during requirements analysis, which would provide input to the SRSs.

3.2.3.3 Behavioral Aspects of the System

A number of technical questions arose during the exercise dry run that related to the correct, reliable operation of the system. The team felt that these issues should be addressed in the preliminary design by means of explicit use of Ada language features. These issues were the clear identification (from the ADL and the graphical representation) of the major control threads running throughout the system; the synchronization and prioritization of concurrent tasks; the avoidance of system-wide deadlock; the effectiveness of the mechanisms used to initialize and terminate the exercise system (these mechanisms can be implicit via reliance on Ada elaboration order or can involve explicitly implemented procedures); and the effective use of Ada exception handling.

3.2.3.4 Interfaces

Interface consistency has typically plagued DOD software development efforts over the years, and the advantages of Ada for producing consistent interface package specifications are obvious. While the team did not really expect that an offeror would fail to use Ada properly for data definition on such a small exercise, the team felt nevertheless that effective use of Ada should be demonstrated in the SEE products.

3.2.3.5 Consistent Representation

The SEE system specification requires that both graphical representation and ADL be used to describe design information and that they be employed consistently. The team found in the SEE dry run that graphical representations are necessary and useful to depict top-level and detailed views of the software architecture as well as relationships among components. ADL is then used to fill in details and to enhance definitions. The team found that these techniques must supplement one another since they lose effectiveness if used to describe different things; consequently, the offerors' SEE products were expected to reflect compatible ADL and graphical design representations.

3.3 EVALUATION TOOLS AND TECHNIQUES

Given the rather low level of detail described above against which the offerors' SEE products would be evaluated together with the potentially large amount of data to be submitted by the offerors, the SEE team identified the possible need for some additional tools and techniques to assist the Government in evaluating the SEE products. To that end, the team recommended that the Government use the ESD acquisition support environment (EASE) and a set of evaluation checklist questions for the SEE source selection.

3.3.1 EASE

EASE is a prototype workstation-based tool intended to support Government review of contract technical documentation. Specifically, EASE, which was under development at the time of the SEE dry run, is oriented towards the review of contractor products relating to the acquisition of Ada software. These products will primarily consist of ADL and Ada code. At maturity, EASE will support a wide range of analytic activities, including RFP preparation, modeling, requirements analysis, design analysis, and tool assessment. EASE is not intended, however, to support management functions.

The EASE prototype executes on a Sun-3 UNIX®[1]-based workstation. EASE takes full

1. UNIX® is a trademark of AT&T Bell Laboratories.

advantage of the Sun's large bit mapped display and windowing system. Different tools execute in their own windows, and information is managed in a common database hidden from the user. At the time of the CCPDS-R source selection, the only tools integrated with EASE were the GNU Emacs editor, the Verdix Ada compiler and several utilities delivered with the compiler.

For the SEE, the team proposed the use of EASE specifically for browsing through the offerors' textual products and for assisting in the evaluation of the ADL submitted with the products. Since the SEE system specification required that the offerors' design be documented in compilable ADL, the team recommended that the Government use EASE to test whether the offerors' ADL did in fact compile. The Government elected to follow these recommendations.

3.3.2 Checklist Questions

In addition to the use of EASE, the SEE team recommended that a set of informal checklist questions be employed to assist the SEE evaluators in their rating of the offerors' SEE products against the factors and standards. The questions would be correlated with specific factors and standards and would highlight particular issues which must be addressed to determine if a standard is met. The questions would serve two purposes: for those source selection evaluators who participated in the dry run, the questions would serve as reminders of key points to look for in the SEE products, and for those evaluators who were not familiar with the SEE prior to source selection, the questions would serve as a checklist for evaluating the products and determining whether or not standards had been met. In support of this recommendation, the SEE team prepared an extensive list of evaluation questions to serve as a basis for the checklist.

3.4 RELEASE OF SEE TO OFFERORS

Based upon MITRE's dry run of the SEE, it was expected that both the offeror preparation of the SEE and the Government evaluation of the resulting products would be intensive and time consuming. Furthermore, the Government resources to review the SEE products would be limited, since the evaluators, about eight people, would most likely be responsible for reviewing both the SEE products and the offerors' technical proposals. Therefore, to give the Government time to review the offerors' CCPDS-R technical proposals and SDPs as well as to give the offerors adequate time to prepare both the technical proposals and the SEE, the Government elected not to begin the SEE until after receipt of the offerors' technical proposals and SDPs. Consequently, the Government did not include the SEE system specification and detailed instructions for the offeror in the RFP released on 10 October 1986; it only included a copy of the SEE section M evaluation criteria and a preliminary set of SEE instructions for the offeror in the RFP instructions for proposal preparation (IFPP). As stated in section 3.2.1, the SEE section M evaluation criteria identified the basis on which the offerors' SEE products would be judged. The preliminary instructions for the offeror contained the general ground rules for the conduct of the SEE and a brief description of the SEE products to be generated and submitted by the offerors for Government evaluation. Upon receipt of the offerors' technical proposals, due on 10 November 1986, the Government planned to supply each offeror the actual SEE system specification and the detailed instructions for the offeror. Figure 5 shows the interaction of Government and offeror activities during the timeframe of source selection. Copies of the SEE system specification and detailed instructions for the offeror, the RFP IFPP preliminary instructions for the offeror, and the RFP section M may be found in appendices A, B, and C, respectively.

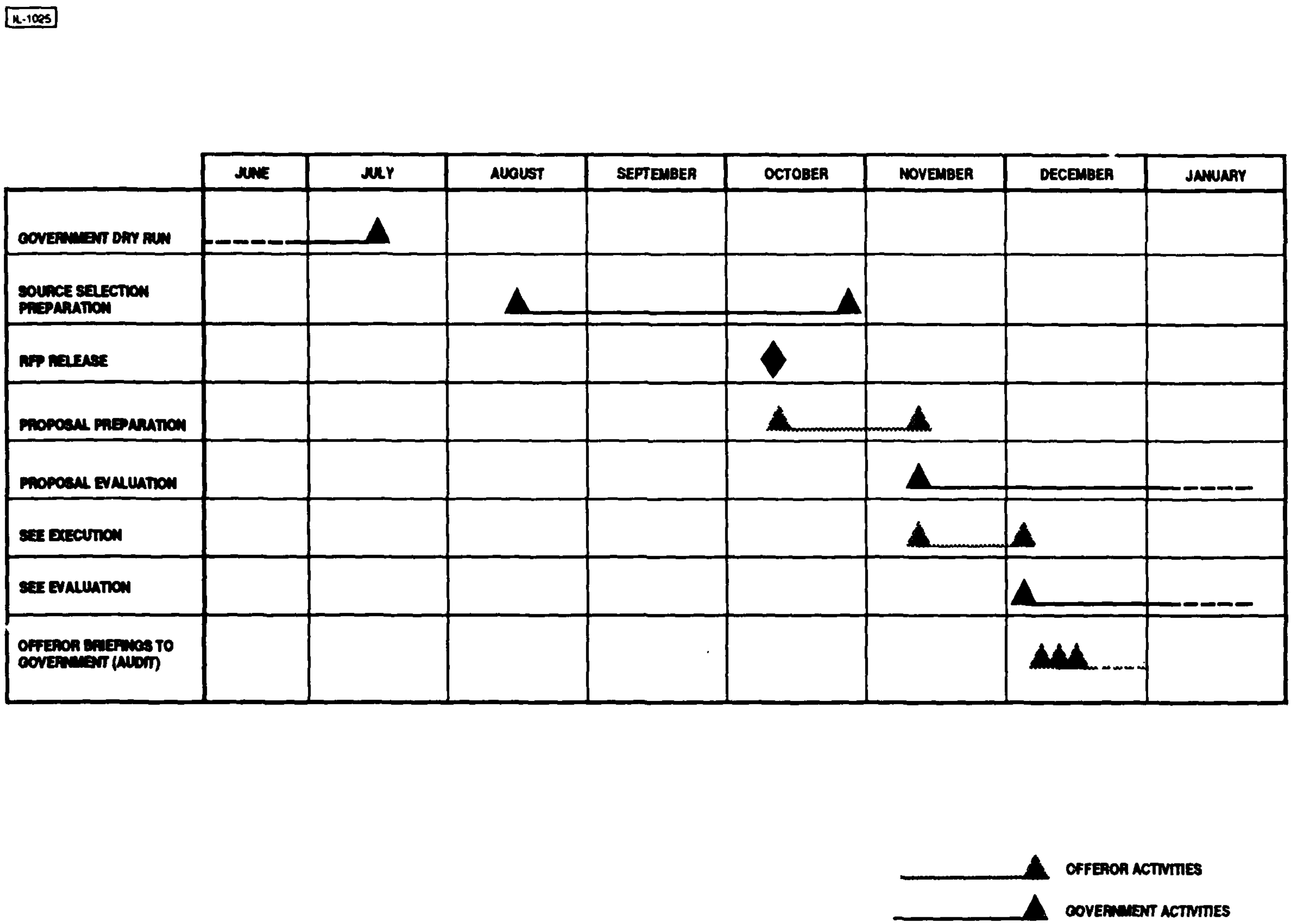


Figure 5. Government and Offeror Activities During the Source Selection Period

3.5 GOVERNMENT EVALUATION APPROACH

The Government's planned approach for evaluating the offerors' SEE products, delivered 3 1/2 weeks after receipt of the SEE system specification and detailed instructions for the offeror, consisted of a first-pass evaluation, an in-house audit at each offeror's facility, and a completed evaluation. The Government's intent was that upon receipt of the offerors' SEE products, the Government would perform a preliminary evaluation of the products, allocating approximately one week for each offeror. Following that evaluation period, the Government would conduct a 1-day audit at each offeror's facility. The offeror's SEE products and results of the audit would then be factored into a final evaluation to be completed by the Government within a week of the audit. The following paragraphs describe the process of the first-pass evaluation and the audit.

3.5.1 First-Pass Evaluation

The purpose of the first-pass evaluation was to obtain a preliminary assessment of each offeror's performance on the SEE and to identify strengths and weaknesses in the offeror's SEE products. The Government would carry out the first-pass evaluation by scoring each offeror's SEE products against the predefined source selection factors and standards. For each offeror, the Government would prepare draft documentation which would describe the offeror's SEE products, the offeror's strengths and weaknesses relative to the factors and standards, and an overall assessment of the offeror's performance on the SEE. Also, the Government would prepare a set of questions tailored for each offeror which would be posed to the offeror during the on-site audit. The intent of these questions was to verify the Government's interpretation and evaluation of the SEE products and to assess the offeror's SEE team capabilities in software engineering, Ada, and the selected methodologies and tools.

3.5.2 Audit

As stated above, the purpose of the Government audit at each offeror's facility was to verify the Government's preliminary assessment of the offeror's SEE products and to obtain additional information to complete its evaluation. As planned, the in-house SEE audit would consist of two parts: an offeror briefing and a question and answer session. The briefing would provide an opportunity for the offeror to explain the methodology proposed for CCPDS-R and employed on the SEE. The briefing would include, at a minimum, a summary of the offeror's management approach, an overview of the requirements analysis approach, an overview of the preliminary and detailed design approaches, an identification of any assumptions made while carrying out the SEE and generating the SEE products, and an identification of any deviations made from the SDP along with the rationale for those deviations.

The briefing would not include any discussion of further work which the offeror may have completed following the submission of the SEE products, since the Government would not evaluate this additional work. The question and answer session would provide an opportunity for the Government to obtain clarifying information about the offeror's SEE products and to query individual offeror team members spontaneously to test their expertise with the selected methodologies and tools. Each member of the offeror's SEE team would be required to be present during the audit to respond to specific questions directed to that individual. The Government would maintain a transcript of the questions and answers. This transcript together with the briefing presentation material and the SEE products delivered at the end of the 3 1/2-week exercise period would be considered part of the offeror's proposal and included in the Government's final evaluation of the offeror's SEE results.

SECTION 4

DRY RUN LESSONS LEARNED

As a result of the MITRE dry run of the SEE, numerous lessons were learned. These lessons may be divided into two categories: administrative issues that relate to defining, organizing and including the SEE as part of the source selection process, and technical issues that concern software development and Ada in general. Lessons learned relating to administrative issues have been described throughout sections 2 and 3. This section summarizes the major technical lessons learned relating to software engineering and specifically requirements analysis, object oriented design, Ada, and DOD-STD-2167. It also highlights how those lessons were factored into either the CCPDS-R FSD/P program and/or the standards prepared for the CCPDS-R source selection.

4.1 REQUIREMENTS ANALYSIS

During the course of MITRE's dry run of the SEE, the team made observations regarding the time allocated for requirements analysis, Government interaction, a formal requirements analysis methodology, and the completion of the requirements analysis phase.

4.1.1 Time Allocation

The team discovered that much more time than anticipated was needed to produce a thorough requirements analysis and associated documentation. As reflected in section 2.3, the team spent approximately three times longer on the requirements analysis effort than originally planned. This extra time was due to the following conditions:

a. The team members initially assumed that the requirements in the exercise specification were clear and would not require extensive analysis;

b. The original 1-week allotment for requirements analysis was overly optimistic but was necessary to achieve the scheduled 15 July 1986 RFP release;

c. The team lacked a formal approach to requirements analysis at the start of the exercise; and

d. The DOD-STD-2167 SRS DID was new, requiring a learning curve, and it specified a lower level of detail than anticipated by the team members.

Eliminating the extra time spent due to conditions a through c above, it was estimated that as much as twice the originally scheduled time was spent on requirements analysis due to the DOD-STD-2167 required level of detail. Based on this observation, the Government developed a projected CCPDS-R FSD/P phase schedule which included approximately one additional month for requirements analysis beyond that typically estimated. Also, the Government elected to scrutinize carefully during source selection the offerors' proposed CCPDS-R software development schedules to ensure that adequate time had been allocated for requirements analysis.

4.1.2 Government Interaction

During the dry run of the SEE, the team observed that the presence of a "Government" representative during the requirements analysis effort greatly facilitated progress during that phase. This person was able to assist the development team by clarifying ambiguities and identifying incorrect assumptions. As mentioned in section 2.7.2.2, the team recognized that the Government could not play a similar role during the offerors' execution of the SEE. However, based upon this SEE observation, the Government elected to include in the CCPDS-R statement of work (SOW) a provision for the Government to maintain a representative on-site in the contractor's facility throughout the requirements analysis phase to monitor the contractor's effort and to assist in obtaining responses to contractor questions.

4.1.3 Formal Methodology

The SEE team found that a formal methodology was needed during the requirements analysis phase to ensure a thorough analysis of the specification functional and performance requirements, and to maintain control over the effort. By formal methodology, it is meant that the methodology be documented, that it cover the areas required in DOD-STD-2167, and that it be teachable. Failure to have such a formal methodology in place and one with which the team was well versed, caused initial delays in the MITRE dry run. Based on this observation, the Government decided to examine the offeror's SEE products to assess the presence of a formal requirements analysis methodology in which the offeror's SEE team was knowledgeable.

4.1.4 Completion of Phase

The SEE dry-run team noted that it was difficult to determine where requirements analysis stopped and design started, especially given the requirements of DOD-STD-2167. For example, the DOD-STD-2167 requirements for the software requirements specification imply that design information related to timing and sizing be included in the SRS (see section 4.4), which is produced during the requirements analysis phase. It was determined that by having a formal requirements analysis methodology and a formal design methodology, and by tailoring DOD-STD-2167, this problem would be minimized. For the source selection therefore the Government planned, first, to scrutinize the offeror's requirements analysis and design methodologies to ensure that they were robust formal methodologies, and, second, to examine the interrelationship of the two methodologies to ensure that they were compatible, with clearly defined steps for transitioning from one phase to the next.

4.2 OBJECT-ORIENTED DESIGN

As mentioned in section 2.2, the MITRE SEE team selected OOD as defined by Grady Booch for the methodology to be used during the design phase. Booch's OOD attempts to map solutions directly to the problem as viewed in real-world terms, forcing a problem set to be viewed in terms of a set of software objects, each with its own set of applicable operations. Booch's OOD consists of three phases: problem definition, informal strategy, and formal strategy. The first phase consists of defining the problem in English at a high level, the goal being to gain an understanding of the structure of the problem space. The second phase consists of developing an informal strategy wherein natural English descriptions of the problem space are used to narrate the problem. The goal of the second phase is to continue expanding the designers' understanding of the problem without limiting their ability to think about the problem and without concerning themselves with the structure of the solution. Finally, the third phase consists of formalizing the strategy. Using the informal strategy developed in the second phase, nouns and verbs are extracted and become the objects and operations in the solution. The nouns are used to imply abstract data types and specific real-world objects. The verbs are used to define real-world operations with particular objects. Also, adverb phrases are extracted to identify attributes of the operations, and interfaces between objects are described. Finally, the operations previously identified for each object are implemented in executable form (e.g., ADL). This process is repeated until a point is reached where the level of decomposition is understandable without further modularity.

During the dry run of the SEE, it appeared to the team that Booch's OOD was an incomplete methodology. While it provided practical guidance for object identification, it lacked support for requirements traceability and completeness, performance analysis, concurrency (i.e., multitasking), initialization and termination conditions, and error detection and handling. It did not clearly specify how to transition from requirements analysis to design nor did it specify guidelines for the completion of detailed design. Furthermore, the team discovered that the use of OOD's informal strategy was non-productive in practice. To have the SRS and then have to write the informal strategy resulted in duplications of effort. The team observed that in many cases the informal strategy could be developed so as to produce contrived results.

As an outcome of these observations, the Government included specific SEE factors and standards to ensure that the offerors' design methodologies were complete, robust, and that they contained specific procedures to resolve the above issues. In particular, the Government planned to assess whether the offerors' design methodologies contained clearly defined procedures for transitioning between requirements analysis and design phases and for handling initialization and termination, exception handling, concurrency, and performance analysis.

4.3 ADA

While dry running the SEE, the team identified several observations relating to both the technical and management aspects of Ada. These issues concerned control flow, ADL, and personnel.

4.3.1 Flow of Control

In a multitasking system, many control flow issues must be resolved. These issues typically relate to shared access to resources, and include deadlock, process starvation, race conditions, serialization, and synchronization. The team spent considerable time addressing deadlock and process starvation, in particular.

Deadlock conditions exist when two or more processes cannot execute because each is waiting for a resource held by another; similarly, process starvation occurs when a process is waiting to access a resource and the scheduling mechanisms either never service the process' request, or result in an unpredictably long delay. In the usual sequential programming languages, operating systems and cyclic executives consider and handle most control flow issues; thus, only the limited group of operating system programmers need address these issues. However, while dry running the SEE, the team discovered that, even at the application level, the Ada tasking construct must be used with great care to avoid deadlock and process starvation; consequently, all applications software designers and programmers must address these issues. To address such conditions within the applications software, the software development methodology must include techniques for designing effective controls for the detection and/or prevention of deadlock and process starvation.

During the dry run, these issues were dealt with in part through the use of canonical task idioms and strategies that provided controlled access to shared resources. Given the team's conclusion about the importance of these control issues and the fact that the SEE subsystem was to be designed using ADL, the Government chose to consider during source selection, as part of the completeness and robustness of the offerors' design methodologies, the ability of the offerors' design methodologies to address flow control, in general, and deadlock and process starvation, in particular.

4.3.2 ADL

The MITRE SEE team designed the SEE system using ADL, documented the design with the ADL incorporated into the DOD-STD-2167 products prepared by the team, and presented the design to the "Government" representatives via the ADL at a mock PDR. The basic conclusion the team reached from these efforts was that the use of ADL by itself does not present a global picture of the entire system to the developers. In its design meetings, the team came to rely on Buhr diagrams as the primary design representation. Moreover, the team found that presenting only ADL at the dry-run PDR failed to convey design information clearly to all reviewers. As a result of this conclusion, the Government modified the CCPDS-R system specification to require the use of graphical notation to convey design information in conjunction with the ADL. Furthermore, since the SEE system specification contained the same graphical notation requirements as the CCPDS-R system specification, the Government opted to consider during source selection, as part of the completeness and robustness of the offerors' design methodologies and clarity and communication of design, the offerors' graphical notation to ensure that it was well-defined, it was consistent with the ADL, and it contained enough features to convey the information available via the ADL constructs.

4.3.3 Personnel

During the course of dry running the SEE, the team encountered several issues related to Ada and personnel. These consisted of personnel training, retention of Ada-trained staff, and presence of Ada experts on development teams.

4.3.3.1 Training

The team observed during the dry run that Ada training must occur at all levels of the software development and acquisition teams; from users, programmers, and designers, to program managers and reviewers. The team also noted that training for Ada programmers and designers is slower and more difficult than training for other programming languages, primarily because Ada imposes the software engineering discipline of a methodology on its users. To a greater extent than in other languages, an Ada programmer must be a software engineer and must be knowledgeable of the methodologies employed, the graphical notation used, ADL, and the Ada language itself. The Ada programmer must be well versed in all these issues at all stages of development; simply learning Ada syntax and semantics is not enough. Based on the SEE dry-run results, the team estimated that training for Ada could be at least two to three times longer than for other languages. Finally, the team concluded that the SEE dry run served as an excellent vehicle to teach Ada as well as software engineering and software acquisition. The SEE dry run served as a far more substantive approach for teaching software engineering and Ada than the typical 5-day courses offered in these areas, which usually concentrate only on theory rather than practical applications. Specifically, the SEE dry run provided team members hands-on training in all aspects of software development, including Ada, methodologies, DOD-STD-2167, requirements analysis, design, and software management. The one major limitation of the SEE dry run was that it did not cover the complete software development cycle since it did not progress all the way through code and testing.

As a result of the above lessons learned, the Government decided to examine the CCPDS-R FSD/P offerors to ensure that the offerors' companies provided in-depth Ada training which was geared for all offeror personnel associated with CCPDS-R software development, as appropriate for assigned roles, and which exceeded the typical 1- to 5-day courses. Furthermore, the Government made plans to train its own CCPDS-R project personnel in Ada after source selection by rerunning the SEE from requirements analysis through testing, with select project personnel serving as the team members, and by having all project individuals participate in at least some typical, formal Ada courses, as appropriate for their given roles and responsibilities.

4.3.3.2 Retention of Ada-Trained Staff

One of the primary risks associated with Ada today is the ability to obtain and retain highly qualified Ada engineers, since the number of such individuals is extremely small. The MITRE SEE team itself experienced problems in these areas during the dry run of the SEE. MITRE had difficulty in assembling a sufficient number of Ada-trained people who could devote a significant amount of time to the SEE, and the SEE team itself experienced the departure of one of the technical leads. As a result of confirming this Ada risk during the SEE dry run, the Government decided to assess each CCPDS-R offeror's ability to assemble and manage a team of engineers for the SEE who were well versed in Ada, as well as the proposed methodologies, software development tools and procedures, and ADL. In addition, to help deter the departure of the FSD/P contractor's key Ada/software engineering personnel, the Government included an award fee plan in the CCPDS-R FSD/P model contract [2]. The contract requires that the contractor flow down 50 percent of the award fee directly to the contractor employees working on CCPDS-R, and not to the company as a whole. As defined, the award fee is tied to the successful completion of specific CCPDS-R milestones.

4.3.3.3 Ada Expert

As mentioned in section 2.1, the MITRE SEE team included two Ada/software engineering experts who were familiar with all aspects of Ada and particularly its more complex constructs. These individuals had significant software development experience as well as a deep understanding of the relevant and often more complex software engineering issues. The presence of these two experts was crucial to the SEE development progress. They served as mentors to the rest of the team and as such were able to keep the rest of the team on track, to point out areas overlooked by the team members, and to answer or resolve detailed software engineering and Ada questions.

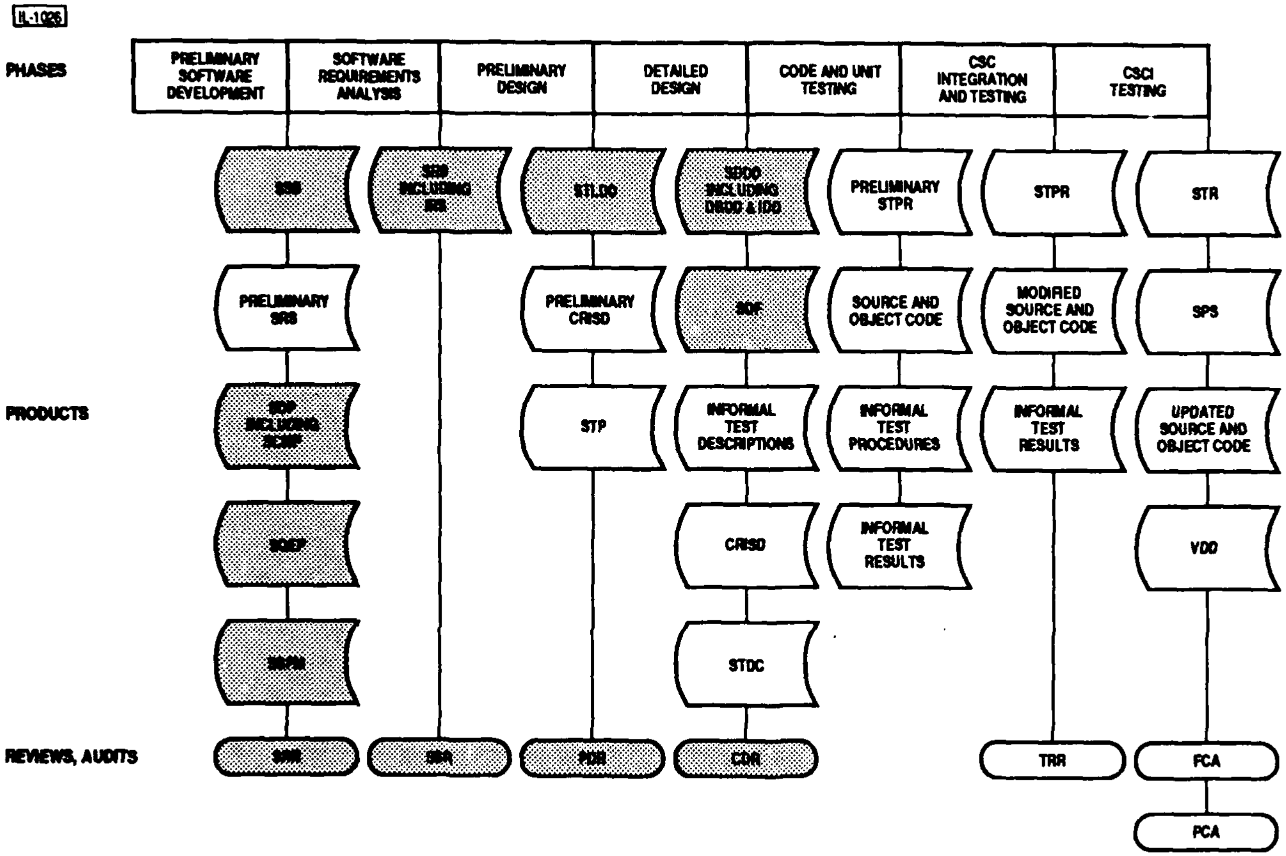
Given the importance of these Ada experts on the MITRE SEE team, the Government concluded that the software development risks on a complex Ada development could be substantially reduced if the contractor's team included at least one or more strong Ada technical leads/experts who were well versed in all the detailed aspects of Ada and software engineering. As a result of this observation, the Government elected to consider, as part of the offeror's team expertise, the offeror's ability to organize a SEE team that included strong Ada/software engineering technical leads.

4.4 DOD-STD-2167

DOD-STD-2167 defines a software development process which is applicable throughout the system life cycle. The system life cycle is divided into phases. Each phase has associated with it one or more products to be generated, and it culminates in a review or audit. The products required at each phase may consist of preliminary or completed products. DOD-STD-2167 is intended to be tailored for each particular application, as necessary. Figure 6 illustrates the DOD-STD-2167 products and reviews with each of the phases as tailored for the CCPDS-R effort, along with an identification of those DOD-STD-2167 products and reviews considered applicable to the SEE.

The SEE team performed the dry run in accordance with DOD-STD-2167, as tailored for CCPDS-R. As the dry run progressed, the team observed that the already existing CCPDS-R tailoring of DOD-STD-2167 required further tailoring because of what the team considered inappropriate requirements of the standard. For example, the DOD-STD-2167 DID for the SRS requires data which seems premature and in some cases impossible to obtain during the requirements analysis stage of development. In particular, the input, processing, and output sections of the SRS DID require the specification of items such as units of measure and ranges for inputs and outputs, the exact intent of the operation, error detection, and algorithms. However, the team found that during the requirements analysis phase, units of measure at this level may be impossible to define and that delineation of the processing section seemed to force the conceptualization of a design, which contradicts the intent of the requirements analysis effort. The SRS DID also requires the specification of timing and sizing data against which the software will be tested, since the SRS is the baseline document for software formal qualification testing to the Government. For current Ada developments, this is almost impossible to do, since previous data on programs developed in Ada is minimal. Thus, the team determined that any timing and sizing estimates entered into an SRS during the requirements analysis phase for an Ada development were especially weak; the possibility was extremely high that the timing and sizing data contained in an authenticated SRS would hold no validity later in the development effort.

As a consequence of these observations, the Government made further modifications of its tailoring of DOD-STD-2167 as contained in the CCPDS-R SOW. The tailoring included, for example, the approach of only baselining the sizing and timing estimates contained in an SRS at the software specification review, but not finalizing these estimates until system PDR, at which time the contractors, through their performance analysis, design, and prototyping efforts would have substantial evidence to support these estimates. A complete tailoring of DOD-STD-2167 for CCPDS-R may be found in the CCPDS-R FSD/P Statement of Work and Contract Data Requirements List [2].



NOTES:

1. DEFINITIONS OF THE ACRONYMS MAY BE FOUND IN THE GLOSARY

2. PRODUCTS AND REVIEWS WHICH ARE SHADED ARE THOSE CONSIDERED APPLICABLE TO THE SEE

3. ALTHOUGH THE SSPM AND SQEP ARE SEPARATE FSD/P DELIVERABLES, FOR THE FSD/P SOURCE SELECTION, OFFERORS WERE REQUIRED TO DELIVER THE SCMP, SQEP, AND SSPM WITH THE SDP. HOWEVER, THE SCMP AND SQEP PORTIONS OF THE SDP WERE NOT CONSIDERED PART OF THE SEE EVALUATION

Figure 6. DOD-STD-2167 Products and Reviews as Tailored for CCPDS-R

SECTION 5

FORMAL CONDUCT OF THE SEE

With the completion of the MITRE dry run of the SEE and the associated SEE exercise specification, ground rules, and evaluation criteria, the Government was fully prepared to conduct the SEE as part of the CCPDS-R FSD/P source selection. This section describes how the Government conducted the SEE relative to the plans described in section 3. It details how the Government released the SEE to the offerors, the products delivered by the offerors, the Government's evaluation team, the tools and techniques the team used to aid in the evaluation of the SEE products, and the Government's overall approach for evaluation of the offerors' SEE products.

5.1 ISSUANCE TO THE OFFERORS

The SEE was issued to the offerors following the plan described in section 3.4. The offerors received a copy of the SEE section M evaluation criteria and a preliminary set of SEE instructions to the offeror in the request for proposal package, issued on 10 October 1986. Upon submission of the offerors' proposals to the Government on 10 November 1986, the offerors received the SEE detailed instructions to the offeror and the SEE system specifications. The offerors were then given 3 1/2 weeks to deliver their SEE products, due on 3 December 1986. For each offeror, the Government spent approximately four days evaluating the delivered SEE products, one day conducting an audit at the offeror's facility, and two days finalizing the evaluation results.

This method of issuing the SEE to the offerors worked out beneficially. First, the offerors benefitted by not having to write their proposals and develop the SEE products at the same time. Second, it allowed the Government SEE evaluation team time during the proposal evaluation period to review each offeror's SDP prior to receiving the SEE products. (The SDP defines the offeror's software engineering approach -- methodology, tool set, ADL, and terminology -- and is the baseline against which the offeror's products were to be evaluated.) If the Government had to review each offeror's SDP and the SEE products at the same time, either the Government would have required a longer time period to review the SEE products (as opposed to 4 days per offeror) or the staff-hours required of the SEE evaluation team would have been overwhelming.

5.2 PRODUCTS RECEIVED

As discussed in section 2.7.2.5, the Government expected the offerors to submit all requirements analysis and design products, both textual and graphic, which the offerors generated as part of their methodology and which are required by DOD-STD-2167, as tailored for CCPDS-R (e.g., software requirements specifications, software top-level design documents, software detailed design documents (SDDDs), performance analyses, etc.); all textual products the offerors generated (e.g., requirements analysis conclusions and documentation, Ada design language listings, etc.) in both hardcopy form and in machine-readable, 9-track tape; and a briefing to the Government on the offerors' SEE results.

In general, the Government did receive most of the expected products from the offerors. In some cases, the Government received documentation that was not required (e.g., diaries of the entire SEE effort). However, the Government did not receive all of the expected "intermediate" products (e.g., data flow diagrams), leading the Government to conclude that in the future the instructions may need to be clarified to ensure that the offerors are aware that the "intermediate" products are required. Overall, the SEE products delivered were of sufficient quality, content and scope to conduct a thorough analysis of the offeror's software engineering capabilities.

5.3 GOVERNMENT EVALUATION TEAM

The Government SEE evaluation team consisted of the Source Selection Evaluation Board (SSEB) and eight technical advisors. The evaluation team was broken down into three groups based on the three factors (methodologies, design, and team expertise) that comprised the SEE technical evaluation item. Each member was assigned to one and only one group, and each group was responsible for evaluating the offerors' SEE products for only that particular assigned factor and associated standards. This division of labor greatly expedited the process of evaluating the SEE products, since it reduced the amount of material any one individual needed to evaluate and, more importantly, it reduced the amount of evaluation assessment documentation that any one individual needed to prepare. Although the SEE evaluation team members were assigned to only one group, all evaluators, regardless of the group to which they were assigned, were permitted and encouraged to provide inputs to any of the three groups/factors. Frequent interaction did in fact occur among the different group members during the evaluation process and resulted in an effective and rapid interchange of technical evaluation assessments.

5.4 EVALUATION TOOLS AND TECHNIQUES

As stated in section 3.3, the Government planned to use the Electronic Systems Division acquisition support environment and a set of checklist questions to assist in the evaluation of the offerors' SEE products.

5.4.1 EASE

The Government intended to use the EASE tool for browsing through the offerors' textual products and for assisting in the evaluation of the ADL submitted with the SEE products. However, due to the limited EASE functionality and logistical problems, the Government used the EASE tool only for verifying that an offeror's ADL was compilable.

5.4.2 Checklist Questions

Although prior to the actual source selection evaluation the Government thought that checklist questions, generated by the MITRE dry-run team, would be used by the evaluators as they were going through the material to determine if factors had actually been met, it was found that this was not what happened during the evaluation. This change in the use of the checklist questions from what was originally intended was made because the checklist questions were found to be too general. It was not until the Government team saw the offerors' actual SEE products that any specific questions could be generated. The checklist questions were thus found to be of minimal benefit, being used only by those evaluators who had not been part of the original MITRE dry-run team as a means of coming up to speed on the type of details the Government was looking for, and by the experienced team members simply as reminders. They were not used as a means to determine whether or not factors and standards had been met, or as the basis for the questions to be asked during the in-house visit.

5.5 GOVERNMENT EVALUATION APPROACH

As discussed in section 3.5, upon receipt of the offerors' SEE products, the Government intended to perform a first-pass evaluation of each offeror's SEE products, lasting approximately one-week per offeror, using each offeror's proposed CCPDS-R FSD/P SDP as the definition of the offeror's software engineering methodology; conduct a 1-day audit at each offeror's facility; and, using the first-pass evaluation and the results of the audit, to produce a final evaluation of each offeror's SEE products within one week of the audit.

5.5.1 First-Pass Evaluation

The Government evaluated the offerors' SEE products against the prepared factors and standards. As a basis for this evaluation, the Government used each offeror's SDP (evaluated during source selection prior to receiving the SEE products), along with any augmentations to it, to determine whether or not the offeror's methodologies, as described in the SDP, were followed during the development of the SEE products. The Government evaluation was to determine not only that each offeror's SDP was followed in the development of the SEE products, but that the requirements analysis and design methodologies defined by the SDPs were adequate.

As strengths and weaknesses in an offeror's SEE products or SDP were identified, vis-a-vis the factors and standards, the evaluators documented them. For those instances where the evaluators could not find the information necessary to evaluate a standard, were not sure of the offeror's motivation or rationale, had any questions about the products, or where the evaluation information could not be ascertained directly from the SEE products delivered, the evaluators prepared questions to be asked during the in-house audit. In addition, the Government evaluation team generated questions to verify its own evaluation of whether or not system requirements had been met.

Although it was originally planned that one list of questions would be prepared for each offeror, and would be presented to the offeror during the question and answer period of the in-house audit, the Government concluded during the first-pass evaluation that the questions for each offeror fell into two categories: those the Government would best benefit from by allowing the offeror 24 hours during which to prepare an answer and those for which the Government would best benefit from by not allowing the offeror more than 5 minutes during which to prepare an answer. Therefore, during the first-pass evaluation, the Government prepared two sets of questions for each offeror based on the results of the Government's evaluation of the following SEE factors.

5.5.1.1 Methodology Factor

Each offeror's requirements analysis and design methodologies were evaluated to ensure that they adequately addressed the major issues in each phase and that the methodologies were compatible. This was accomplished by reviewing the SEE products to determine if the methodologies were robust and cohesive and to ensure that the methodologies were consistent with each other and provided a distinction between the end of requirements analysis and the beginning of design. A methodology was considered robust if it adequately and completely addressed modern software engineering issues for a real-time system. Attributes of the SEE products that contribute to requirements analysis methodology robustness include, but are not limited to, inclusion of performance analysis during requirements analysis, detection, and resolution of specification ambiguities known to exist in the SEE system specification, effective employment of measures for tracing requirements, and identification of derived requirements. In addition, the SEE products were reviewed to ensure that the SEE products contained acceptable ADL and graphical representations consistent throughout the SEE products. Questions generated for the in-house audit were intended to clarify methodology questions.

5.5.1.2 Design Factor

Each offeror's design was evaluated to ensure that it addressed all of the functional and quality requirements contained in the SEE system specification, as appropriate, for the subset of the architecture which the offeror elected to design; that it demonstrated sufficient structure to support modularity, flexibility, and ease of change and growth; and that it demonstrated no deadlock or race conditions. The design was also evaluated to ensure that it employed effective approaches for managing data and control flows; for handling initialization, termination, and exceptions; and for meeting performance and capacity requirements. For this factor, the evaluation team generated questions for the in-house audit which were intended to clarify design questions and to verify the Government's evaluation of whether or not certain SEE system specification requirements were met.

5.5.1.3 Team Expertise Factor

Based on the results of the exercise, the Government evaluated the offerors on their compliance with the SDP, on the knowledge demonstrated by the offerors' SEE team members of their SDP policies and procedures and their tools, and on the offerors' proper use of Ada as a design language to represent the design. The offerors were also evaluated to assess whether their teams consisted of individuals well versed in software engineering and real-time applications, and whether the teams included strong software engineering/Ada technical leaders. The Government evaluated the offerors on their teams' knowledge of the SDP policies, tools, software engineering, and real-time applications via the responses to the "five-minute," spontaneous questions posed to the offerors during the in-house audit. By addressing many of the spontaneous questions to particular offeror SEE team members, the Government was able to determine the knowledge of an offeror's entire SEE team and not just that of those members whom the offeror chose to have respond.

5.5.2 Audit

Following the first-pass evaluations, the Government conducted a 1-day audit at each offeror's facility. As discussed in section 3.5.2, the purpose of the Government audit was to verify the Government's first-pass evaluation and to obtain additional information necessary to complete the SEE evaluation. The offerors were required to prepare a briefing of their SEE conclusions, and to answer the Government's questions. The offerors were evaluated during the in-house audit based on their ability to provide the required information during the in-house briefing and adequate answers during the question and answer session.

In accordance with the procedures defined in section 5.5.1, the Government submitted two sets of questions to the offerors for the in-house audit. One set of questions was submitted 24 hours in advance, for which the offerors were required to respond during the audit as well as to provide formal, written responses to the Government. The other set of questions was given to the offerors 5 minutes in advance, for which the offerors were required to respond immediately and for which the Government maintained a record via cassette tape.

5.5.3 Evaluation Completion

Following the in-house audit at each offeror's facility, the Government easily completed its evaluation of the offerors' SEE products within a week of the in-house audit. The completion consisted of updating the first-pass evaluation assessments and associated identification of strengths and weaknesses to reflect the additional, clarifying information obtained from the in-house audit. In addition, the Government transcribed the cassette-recorded responses to the spontaneous "five-minute" questions. The transcripts, together with the formal responses to the "twenty-four hour" questions were then entered into the offerors' official submission of SEE products.

SECTION 6

SOURCE SELECTION LESSONS LEARNED

As a result of conducting the SEE during the CCPDS-R FSD/P source selection, the Government identified a number of lessons learned concerning the administration of a software engineering exercise. These lessons learned relate to deliverable products, exercise scope and duration, Government evaluation tools and techniques, and Government evaluation approach. The lessons learned, presented herein, are intended to describe not only how the SEE might be changed for future use or what did not work out as well as possible, but also to discuss those aspects of the SEE that did work well and should be repeated in the future.

6.1 DELIVERABLE PRODUCTS

In some cases, offerors did not submit all "intermediate" SEE products (e.g., data flow diagrams) which were expected by the Government. Therefore, future programs which elect to carry out a SEE may need to evaluate their instructions to the offerors to see if they must be clarified to ensure that the offerors are aware that all requirements analysis and design products, including "intermediate" products, are deliverable to the Government.

6.2 EXERCISE SCOPE AND DURATION

As a result of the use of the SEE during source selection, the Government concluded that the time, level, and the coverage of the SEE was adequate. The volume and depth of the offerors' delivered SEE products indicate that 3 1/2 weeks was sufficient time.

It was apparent during the evaluation of the offerors' performance on the SEE that it did provide the Government with the answers it was looking for concerning the offerors' ability to assemble a SEE team and address software engineering and Ada issues, in the context of the offerors' SDP. The level of requirements in the system specification provided the opportunity for the offerors to demonstrate their ability in the pertinent areas (e.g., real-time system design, modern software engineering practices, Ada). It is not felt that a more difficult set of requirements would have added anything to the Government's knowledge of the offerors' ability. To have increased the coverage of the SEE requirements, or to have broadened the system, could have had the negative impact of forcing the offerors to cover more area with less depth. The Government feels that no significant amount of new evaluation information would have been gained, had more time been allocated to the offerors for completing the exercise. More ADL might have been generated, or the products might have been more complete, but it would not have added anything to the Government's assessment of the offerors' ability to perform requirements analysis and design a real-time system.

6.3 EVALUATION TOOLS AND TECHNIQUES

As mentioned in section 5.4, the Government used the ESD acquisition support environment and a set of checklist questions to assist in its evaluation of the offerors' SEE products. In addition, the Government relied heavily on word processors to expedite its evaluation and associated documentation efforts. The Government made the following observations regarding the use of these tools during the evaluation of the offerors' SEE products.

6.3.1 EASE

As discussed in section 5.4, EASE use was attempted and largely abandoned during source selection. The Government had trained a large portion of the evaluation team in the use of EASE; however, the investment was not worth the return due to the limited EASE functionality and the logistical problems associated with using a computer facility remote from the source selection. The team members also felt that EASE was not really essential, given the volume of SEE materials submitted.

At the time of the CCPDS-R FSD/P source selection, EASE provided text editing and Ada compilation functions, but did not provide tools to assist in identifying control flows and data flows, perform syntax-related browsing and cross-referencing, or assess compliance to coding/design standards. It required significant manual overhead for such activities as loading tapes and providing backups, and because EASE was not collocated with the source selection facility, there was time-consuming travel to transport materials to the EASE facility for evaluation. The EASE facility also had to be locked and other EASE users could not have access while source selection sensitive materials were installed. Not until these largely logistical deficiencies can be overcome will EASE and similar tools become useful tools for SEE evaluations. Therefore, before using EASE or similar tools on future software engineering exercises, programs should first assess the functionality, ease-of-use, logistics, and potential benefits. If the selected tool is deficient in any of these areas, then its exact use during the evaluation should be clearly specified prior to source selection. If programs opt to use automated tools in the future, regardless of whether or not any of these deficiencies still exist, these programs should consider training fewer evaluation team members since the cost and time required to undergo such training is likely to be significant.

6.3.2 Checklist Questions

As discussed in section 5.4.2, the Government concluded that the checklist questions prepared prior to source selection did not prove as useful as had been anticipated and were not worth the amount of time it took to prepare them. As an evaluation tool, the questions were not very beneficial and serious consideration should be given to either not using them or not investing so much time in preparing them.

6.3.3 Word Processing Capabilities

At the start of the evaluation of the offerors' SEE products, the Government SEE evaluation team had only minimal word-processing capabilities. As the evaluation continued, more word-processing capability was secured, and though it was helpful, it was still not at an adequate level. For the CCPDS-R FSD/P source selection, the SEE evaluation would have been expedited if there had been a separate word processor for each of the three groups which made up the team. A laser printer capable of producing letter-quality text and viewgraphs is also necessary. In the future, programs conducting a SEE should ensure that sufficient word-processing capability is provided so that there is no contention of resources when documenting the SEE evaluation results against the factors and standards.

6.4 IN-HOUSE AUDIT

As a result of conducting the in-house audit, the Government concluded that a 1-day audit at the offerors' facilities was both beneficial and of sufficient time. Future programs which institute software engineering exercises are strongly encouraged to conduct such audits if time and logistics permit. Furthermore, as a result of conducting the in-house audit, the Government made several observations regarding the submission of detailed questions to the offerors and the maintenance of a transcript of offeror responses.

6.4.1 Detailed Questions

As discussed in section 5.5.1, the Government altered its method for presenting detailed questions to the offerors as a result of the first-pass evaluation. The revised approach, consisting of two sets of questions, one submitted 24 hours in advance and one 5 minutes in advance, proved successful; its use is therefore recommended for other programs that may conduct a SEE audit. In the case of the 24-hour set, the Government was able to get answers to questions that the offerors could not have answered as completely or in as much detail if they had not had some time to prepare. For the 5-minute set, the Government was able to evaluate the offerors based on their ability to answer questions extemporaneously which should have required no preparation time, assuming the offerors' teams were fully trained in the methodologies as claimed in their proposals. The Government was able to direct many questions to particular offeror SEE team members based on their area of responsibility on the SEE, lending substance to the evaluation of the offerors' entire SEE team. The use of two sets of questions for the offerors provided discriminating information that could not have been attained through the use of only one set of questions.

6.4.2 SEE Transcripts

As mentioned in section 5.5.3, the Government completed its evaluation of the offerors' SEE products by updating the first-pass evaluations to reflect the audit results. Transcripts of the offerors' recorded spontaneous audit responses, together with the offerors' formal responses to the "twenty-four hour" questions were entered into the offerors' official SEE product submissions.

In general, this approach to completing the SEE evaluation worked well. The one major drawback was the method chosen for documenting the offerors' responses to the spontaneous questions. Originally, the SSEB planned to have the offerors maintain the written transcripts of these responses, but this decision was overruled. Consequently, the CCPDS-R FSD/P SSEB had to maintain the transcript. However, transcribing the cassette tapes placed an overwhelming burden on the limited SSEB resources since it was such an extremely tedious, time-consuming process. Therefore, it is suggested that in the future, if SEE audits are held, that either the SSEB be allowed to have the offerors maintain the written transcripts or that some alternative method be found, such as only requiring magnetic recordings or videotapes of the responses.

SECTION 7

OFFEROR FEEDBACK

In addition to making its own observations regarding administering and conducting a software engineering exercise, the Government solicited feedback from the CCPDS-R FSD/P offerors on their impressions of the SEE. The Government accomplished this by providing to the offerors an optional questionnaire at the conclusion of the in-house audit (see appendix D). In general, the offerors responding to the questionnaire felt that the SEE was a valuable exercise. This section summarizes the offeror feedback, addressing the areas of the size of the SEE, the exercise appropriateness, the resources expended, and the benefits to the offerors.

7.1 SIZE

On the average, the offerors considered the size of the SEE to be of an appropriate level, both in terms of the time required and the time allowed by the Government, and in terms of the SEE system that the offerors were required to design. The offerors made no recommendations to either increase or decrease the scope of the SEE or the time allotted for it.

7.2 APPROPRIATENESS

Generally speaking, the offerors considered the SEE to be a challenging, appropriate exercise in relation to CCPDS-R FSD/P source selection. The offerors indicated that the focus of the SEE on requirements analysis and design was very appropriate because of the perceived high level of risk associated with the requirements analysis and design of an Ada system. Some offerors felt that metrics should have been included in the SEE, since metrics collection, reporting, and evaluation are integral to program management. Additionally, some offerors felt that not enough opportunity was provided to demonstrate products that they had expended resources on (e.g., prototypes) for use in CCPDS-R FSD/P.

7.3 RESOURCES

On the average, the offerors considered the resources expended on the SEE to be of a reasonable level. The percentage of time allotted by the offerors was fairly equally divided between each of the phases (i.e., requirements analysis, top-level design, detailed design, and preparation for and participation in the in-house audit). The average amount of resources expended by the offerors was a little less than 1 staff-year.

7.4 BENEFITS

Overall, the offerors assessed the SEE as beneficial, for several reasons. First, the SEE provided the offerors an opportunity to exercise and refine their software engineering methodologies.

Prior to the SEE, the requirements analysis and design methodologies included in the offerors' SDPs had not been fully utilized. The SEE provided an opportunity for the offerors to exercise their methodologies on an actual, albeit small, program and to receive feedback internal to the offerors' organizations on those methodologies and the products delivered as a result of utilizing them. This feedback provided the offerors with an opportunity to refine their methodologies where necessary, prior to utilizing them on a large program such as CCPDS-R. Second, the SEE provided an actual illustration of the benefits of various software engineering approaches (e.g., prototyping, reusable components, etc.). This provided offeror insight into the value of these approaches and/or the need to modify these software engineering approaches for CCPDS-R FSD/P. Third, the SEE provided CCPDS-R related experience which can then be applied to the CCPDS-R FSD/P phase. Finally, successfully accomplishing the SEE using their chosen methodologies and Ada provided the offerors with increased confidence in those methodologies, their Ada expertise, and their software development core team.

SECTION 8

CONCLUSIONS/RECOMMENDATIONS

Overall, both the SEE dry run and the incorporation of the SEE into the FSD/P source selection were successful. This section summarizes the Government's conclusions and recommendations resulting from this successful CCPDS-R SEE, first from the perspective of the dry run of the SEE and then from the actual use of the SEE during source selection.

8.1 DRY RUN

The Government assessed the dry run of the SEE as extremely beneficial, given the lessons learned from that effort. More importantly, however, based on the results of the dry run, the Government determined that the software engineering exercise demonstrated strong potential for being an effective and discriminating source selection technique. This section summarizes the Government's pre-source selection SEE conclusions and recommendations relative to the dry-run objectives, software engineering, and Ada.

8.1.1 Objectives

As stated in section 2, the primary objectives of the MITRE SEE dry run were to generate a clearly defined SEE system specification, to develop the ground rules for the offerors to follow when conducting the SEE, to identify a discriminating set of evaluation criteria, and to assess whether the SEE could reasonably be done in the time allotted to the offerors. The secondary objective was to educate staff in software methodologies, Ada, ADL and DOD-STD-2167. The SEE dry run achieved all these objectives satisfactorily. As a result of dry running the SEE, the Government was able to

a. Analyze the draft SEE system specification thoroughly, identify weaknesses in the draft specification, resolve these weaknesses, and generate a final, concise SEE system specification that contained heretofore omitted requirements pertinent to CCPDS-R, that would serve as key technical discriminators

b. Develop a set of offeror instructions by which the Government scoped the SEE, expedited both the offeror preparation effort and the Government evaluation, and maintained the fairness and objectivity of the SEE effort

c. Identify a low level set of technical discriminators geared specifically to the SEE system specification and Ada, which the Government felt would enable it to separate form from substance in the offerors' results and thus distinguish those offerors who have strong software engineering/Ada capabilities from those who do not

d. Verify that the SEE, as scoped per the detailed offeror instructions, could reasonably be done within the 3 1/2 weeks allotted to the offerors

e. Gain further knowledge, depending on the skill of the individual SEE team member, in requirements analysis and design methodologies, Ada, ADL, DOD-STD-2167, all of which would prove useful to the CCPDS-R program office during both the source selection and the FSD/P phase.

MITRE expended approximately fifteen staff months of effort dry running the SEE, from initial conceptualization of the SEE to completion of all SEE RFP documentation. Thus, the Government considered the SEE dry-run effort somewhat costly; however, the Government considered that the benefits far outweighed the costs. Since the SEE was a new source selection technique at ESD, the Government considered the dry running of the SEE mandatory to test out the concept of the SEE, to verify that the SEE was a reasonable and workable source selection technique, and to ensure the overall success of the SEE as a source selection technique for CCPDS-R and other future programs. Moreover, by dry running the SEE, the Government was better able to identify specification requirements and evaluation criteria it felt would serve as true discriminators during source selection and to train staff in software engineering methodologies and Ada for both present and future use. Given these benefits, it is strongly recommended that when a program includes a software engineering exercise as part of its source selection approach, it dry run the exercise to some extent before the release of the exercise to offerors. As a minimum, the dry run should focus on the generation of an appropriate system specification and on the development of discriminating evaluation criteria.

8.1.2 Software Engineering and Ada

A number of software engineering and Ada lessons learned resulted from the MITRE SEE dry run. The major conclusions and associated recommendations are as follows:

a. More time is needed for requirements analysis than is traditionally allocated. This extra time is due to the difficulty of correctly interpreting user requirements and intentions, as well as the increased level of detail required by DOD-STD-2167. Programs with a large software development component should therefore plan appropriately for this additional time.

b. Daily/weekly Government participation during the contractor's requirements analysis effort may facilitate progress during that phase by helping to clarify specification ambiguities and prevent incorrect assumptions by the contractor. It is therefore suggested that software acquisition programs consider having Government representatives on site during the contractor's requirements analysis effort to expedite those activities.

c. Object oriented design as defined in Booch's "Software Engineering with Ada" provides useful guidelines but does not constitute a complete methodology. Consequently, programs using Booch's OOD should either augment it to overcome the shortfalls in it or should seek other alternative methodologies. Alternative methodologies should also be scrutinized for completeness.

d. DOD-STD-2167 appears to require specification and authentication of data (e.g., timing and sizing information) which seems premature and in some cases impossible to answer for the given stage of development. This problem seems especially true for Ada developments for which no previous data is available upon which decisions and estimates can be made.

Therefore, programs using DOD-STD-2167 should consider tailoring the standard so that specification and authentication of data occurs at achievable and realistic milestones.

e. With the Ada language and its tasking construct, applications software, and not just operating system software, must consider and handle control flow issues such as deadlock and process starvation. Thus, programs using Ada should ensure that the software development methodologies employed on the program include techniques for designing effective controls for the detection and/or prevention of deadlock and process starvation.

f. An Ada-based design language by itself is not a sufficient tool for effecting clarity and communication of global system design information either among developers or between developers and the Government. Hence, programs using ADL should require that a graphical design representation technique, consistent with the ADL, also be used for portraying design information.

g. Availability and retention of qualified Ada engineers constitutes a high risk on Ada developments. Consequently, programs using Ada should investigate the use of different contracting vehicles and incentives to obtain and retain qualified Ada engineers both within the Government agencies and the contractors' organizations.

h. For programs using Ada, Ada training must occur at all levels of the software development and acquisition teams. Proper training in Ada, however, takes longer than for other languages. Therefore, programs designing and/or implementing in Ada should require extensive Ada training for both Government and contractor personnel, as appropriate, and should plan and account for any additional time and effort required to do so.

The Government also concluded that a software engineering exercise serves as an extremely effective vehicle for training personnel in all aspects of software acquisition and software engineering. The unique benefit of the SEE as a training approach is that it provides practical, interactive, hands-on experience not offered in typical non-interactive theoretical courses, and it covers a range of issues, such as requirements analysis methodologies, design methodologies, Ada, DOD-STD-2167, software specifications and reviews, and software tools and technique. While the SEE is an effective training technique, it is costly to conduct since participants must dedicate significant amounts of time and effort to reap the benefits. However, the benefits are considered to far outweigh the cost.

8.2 ACTUAL SOURCE SELECTION

At the start of the CCPDS-R FSD/P source selection, the Government considered the purpose of the SEE to provide discriminating information that would enable the Government to determine the degree of risk associated with each CCPDS-R offeror's proposed software development methodology and to determine the offeror's ability to organize a team fully knowledgeable in that methodology and in Ada, the required CCPDS-R implementation language. This section provides a summary of the conclusions the Government reached regarding the SEE versus its CCPDS-R objectives. It also provides some general observations regarding the conduct of future software engineering exercises.

8.2.1 CCPDS-R SEE Objectives

At the completion of the FSD/P source selection, the Government concluded that the CCPDS-R SEE satisfied its objectives resoundingly. General conclusions regarding the CCPDS-R SEE as a source selection technique may be summarized as follows:

a. The SEE was an extremely beneficial source selection technical area evaluation technique. By having offerors develop actual products using their proposed software development approach, the SEE provided the Government invaluable insights as to what an offeror really can do versus what an offeror claims he can do. It provided a concrete example that demonstrated the degree of robustness of an offeror's methodology, the offeror's ability to follow the proposed SDP, and the offeror's expertise in the proposed methodology and tool set. It clearly demonstrated whether or not an offeror's proposed CCPDS-R FSD/P team had sufficient expertise to design and develop a real-time system in Ada, as is required for CCPDS-R.

b. The SEE served as an excellent vehicle by which to identify early problems in an offeror's software approach. For example, the use of the SEE helped to point out incomplete methodologies that did not address all of the software engineering issues, areas where the requirements analysis and design methodologies conflicted, and inadequate ADL and graphical design representation techniques. By uncovering these problems during source selection, the Government was better able to focus on these problems immediately at FSD/P contract award, rather than waiting until they become apparent in the development phase, when problems are more costly and difficult to correct and the contractor is less willing to make changes.

In addition to meeting its stated objectives, the SEE also provided some additional benefits not originally anticipated. In particular, the SEE assisted in the source selection cost area evaluation by yielding valuable information on offeror capabilities in such areas as level of experience with the selected programming language and tools. This additional insight into actual offeror capabilities enabled the Government to generate more representative inputs for its software cost estimation models and thereby to assess cost and schedule risk associated with an offeror's software development approach for the CCPDS-R FSD/P phase. Also, as the offeror feedback indicates, the SEE forced offerors to solidify and test out their methodologies and teams and thus to make modifications, as appropriate, to eliminate problems on their own prior to the FSD/P phase.

8.2.2 General Observations

Given the overwhelming benefits that were reaped from the CCPDS-R FSD/P SEE, the Government SEE team strongly recommends the use of a software engineering exercise for other acquisition programs. However, the team does so with the following caveats:

a. To conduct a software engineering exercise is costly, both for the Government and for the offerors. For the CCPDS-R SEE, the Government expended approximately twenty staff-months to dry run the SEE and to evaluate the offerors' SEE products during source selection. Offerors expended approximately ten staff-months each to carry out the exercise. As the Government becomes more used to conducting SEEs, the level of Government effort expended will decrease, perhaps to ten staff-months. However, in any case, if a program elects to conduct a software engineering exercise, it should be aware of and able to accommodate the additional cost.

b. Evaluation of a software engineering exercise may add significant time to a source selection if many offerors respond or if the Government evaluation team is not well prepared in advance. Consequently, programs that opt to conduct a SEE should consider approaches for minimizing the time required to conduct and evaluate a SEE. Possible approaches include staggered release of the exercise, Government dry running of the exercise as was done for CCPDS-R, and strong technical and management teams to evaluate the SEE products.

c. A software engineering exercise is of benefit to a particular program's source selection only if it is tailored for that program. For example, providing a missile warning exercise on a local area network (LAN) program would be of little value since the offerors, most likely communications software engineers, would not be evaluated on those LAN-unique software areas which would truly demonstrate the offerors' capabilities to implement the real program. Also, a software engineering exercise is beneficial only if it has specific, realistic goals in mind. For example, in the case of CCPDS-R, concern existed that not all offerors would be proficient in designing a missile warning, real-time system in Ada, as is required for CCPDS-R. The CCPDS-R SEE and associated evaluation criteria were specifically devised to address this concern. Therefore, if a program does choose to conduct a software engineering exercise, it should ensure that the exercise is applicable to the real program and that it is geared towards discerning particular, discriminating information about the offerors.

d. While a software engineering exercise provides discriminating source selection information, it cannot be relied upon solely as a means to select a contractor. For example, situations may occur, such as offerors not following the ground rules and using resources not proposed in the SDP, which may invalidate the SEE results and consequently its usefulness as an evaluation item. Thus, programs which elect to carry out a software engineering exercise should include other evaluation items besides the exercise upon which to make a source selection decision.

In some respects, the CCPDS-R program was fortunate in that it was the first program at ESD to conduct a software engineering exercise. Consequently, industry was not sure what to expect and, therefore, industry followed the SEE instructions completely and satisfied the SEE intent fully. However, as software engineering exercises become more common, the response of industry may be to develop "professional exercise teams" analogous to the specialized proposal preparation teams now evident, or to bring in outside consultants or employ other similar vehicles (e.g., submitting too much material) which will in essence circumvent or negate the intent of the exercise. Future programs that choose to conduct software engineering exercises must be aware of this possibility and thus take additional precautions where necessary to prevent this situation from arising during source selection.

LIST OF REFERENCES

1. Department of Defense, "Military Standard: Defense System Software Development," DOD-STD-2167, 4 June 1985.

2. Headquarters, Electronic Systems Division, "RFP F19628-86-R-0142, Amendment 001, CCPDS-R FSD/P," 10 October 1986.

3. Booch, G., *Software Engineering With Ada*, Menlo Park, California: The Benjamin/Cummings Publishing Company, Inc., 1983.

4. Buhr, R., *System Design With Ada*, Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1984.

5. Headquarters, U. S. Air Force, "Contracting and Acquisition: Source Selection Policy and Procedures," AF Regulation (AFR) 70-15, 22 February 1984.

6. Headquarters, Electronic Systems Division, "Contracting and Acquisition: Source Selection Policy and Procedures," ESD Supplement 1 to AFR 70-15, 21 March 1986.

APPENDIX A

SEE INSTRUCTIONS FOR THE OFFEROR AND EXERCISE SPECIFICATION

This appendix contains the detailed instructions for the offeror and the CCPDS-R SEE system specification provided to the offerors upon receipt of the CCPDS-R FSD/P proposals.

CCPDS-R SOFTWARE ENGINEERING EXERCISE

Detailed Instructions for the Offeror

1.0 PURPOSE

The purpose of the software engineering exercise (SEE) is to permit the Government to evaluate an actual application of each offeror's software development methodology as proposed for use during the CCPDS-R full-scale development/production (FSD/P) phase. The SEE will concentrate exclusively on the offerors' approach to requirements analysis, design, and their interrelationship. The Government will not evaluate as part of the SEE the offeror's approach to implementation, integration, test, quality assurance, configuration management, staffing level, productivity measures, software metrics collection, and other development activities not explicitly mentioned in the following paragraphs.

2.0 INSTRUCTIONS FOR THE OFFERORS

Each offeror will provide a prototypical example of his proposed software development approach, as applied to a sample problem taken from the missile warning domain. [The attachment], "Exercise Specification," presents the requirements for the sample problem. In performing the exercise, the offeror shall comply with all provisions of his proposed software development plan and with section 3.3 of the CCPDS-R system specification. To the maximum extent practical, the offeror shall make use of development tools and procedures that are proposed for the CCPDS-R FSD/P phase, as this will be viewed more favorably by the Government; deviations shall be noted by the offerors.

Participation in the exercise shall be limited to those individuals identified in the offeror's proposal as part of the CCPDS-R full-scale development team. Subcontractors who will be responsible for software development on CCPDS-R shall be active participants. Consultants shall be precluded from participating. Each offeror will deliver to the Government all requested materials, in the formats described in section 3, no later than 12 noon local time, 3 December 1986. The Government will review this material for a period of time not to exceed two (2) calendar weeks. Following completion of the Government review, a Government team will conduct an on-site visit at the offeror's facility, at which time the offeror shall brief his approach and provide responses to Government requests for clarification. The Government will coordinate the schedule for the on-site visit with the offeror upon receipt of the offeror's exercise results. Preliminary plans are for the Government to conduct the on-site visit during the week of 15-19 December 1986. Note that there will be no interaction between the offeror and the Government during the offeror's implementation of the exercise. Should the offeror have any questions on the exercise, the offeror is instructed to identify appropriate assumptions, to document these assumptions, and proceed with the exercise based on those assumptions.

The Government will conduct its evaluation of the offeror's delivered materials and assess the offeror's proposed methodologies using as a primary reference the offeror's Software Development Plan (SDP) submitted with the CCPDS-R proposal, and particularly the software standards and procedures contained within the SDP. The offeror may submit with the SEE materials delivered on 3 December 1986 an augmentation to the SDP, not to exceed fifteen (15) pages, which provides further concise, technical, and explicit details regarding the offeror's proposed software development approach and methodologies. The Government will consider any such augmentation as part of the offeror's proposal and subject to Government evaluation.

The Government will employ automated tools to conduct its evaluation of the offeror's delivered materials. Therefore, as described in section 3, the offeror is required to deliver some of the exercise products in machine-readable format. In order to assess the compatibility of the Government's tools and the offeror's machine-readable products, the offeror is requested to deliver to the Government no later than 12 noon local time, 19 November 1986, a demonstration tape containing sample files of the offeror's methodology products (e.g., Ada-based design language (ADL) listings, etc.) in the same format as will be submitted at the conclusion of the exercise period. The Government will not evaluate the contents of this demonstration tape, but will merely use the tape to study and resolve any compatibility issues that may develop between the Government's tools and the offeror's tape output. The sample files on the demonstration tape do not need to represent actual products of the exercise; they need only represent general products of the offeror's proposed methodologies, the types of which the offeror will submit for evaluation at the end of the exercise period.

3.0 PRODUCTS OF THE EXERCISE

At the conclusion of the exercise period on 3 December 1986, the offeror shall deliver the following items to the Government for evaluation:

a. A complete software architecture for the sample problem. This architecture shall contain an identification of software components, an allocation of functions to these software components, a preliminary specification of interfaces, and an indication of control and data flow throughout the system.

b. For two or more offeror-selected components of the system, all requirements analysis conclusions reached and documentation. With respect to the selected components, the requirements analysis shall represent a complete utilization of the tools and procedures proposed by the offeror for use on CCPDS-R. The offeror shall identify any deviations from these tools and procedures and the associated rationale for these deviations in his briefing to the Government.

c. For two or more offeror-selected components of the system, all preliminary design documentation, including requirements traceability, ADL listings, and graphics products. With respect to the selected components, the preliminary design documentation shall represent a complete utilization of the tools and procedures proposed by the offeror for CCPDS-R. The offeror shall identify any deviations from these tools and procedures and the associated rationale for these deviations in his briefing to the Government.

d. For at least one offeror-selected component of the system, all detailed design documentation, including requirements traceability, ADL listings, and graphics products. With respect to the selected component(s), the detailed design documentation shall

SEE DETAILED INSTRUCTIONS (Continued)

represent a complete utilization of the tools and procedures proposed by the offeror for CCPDS-R. The offeror shall identify any deviations from these tools and procedures and the associated rationale for these deviations in his briefing to the Government.

All textual products of the exercise, including requirements analysis conclusions and documentation, ADL listings, and other design documentation shall be delivered to the Government both in hardcopy form and in machine-readable, 9-track tape. Exception will be made for materials that the offeror does not propose to create and/or maintain online during the CCPDS-R FSD/P contract. In particular, graphical representations shall be submitted in hardcopy form. The tape shall be in 9-track 1600 bpi format in accordance with ANSI X3.27-1978, ASCII labelled, and with an identified record size and block size. The block size shall be 512 bytes. For readability, all tabs should be expanded to spaces. The offeror shall provide ten (10) copies of all hardcopy products. The products delivered shall be clear, coherent, legible, and prepared in sufficient detail for effective evaluation. Elaborate documentation, expensive binding, detailed art work or other embellishments are unnecessary. The offeror shall include with these products indices delineating the subject and contents of the hardcopy material package and the 9-track tape; the operating system command(s) used to create the tape; a list of ADL compilation units; and a list of the compilation order of these units.

In addition to the delivered products described above, the offeror shall provide a briefing to the Government during the on-site visit that summarizes his experience in carrying out the exercise and describes the products generated. The briefing shall not exceed three (3) hours in duration. The topics presented shall include the following:

I. Management approach, to include:

   A. Introduction of team members
   B. A description of individual roles and experience

II. An overview of the requirements analysis approach, to include:

   A. A rationale for the selection of the software components
   B. A description of the tools and procedures employed
   C. Significant requirements issues encountered and their resolution
   D. A discussion of deviations from the proposed approach, and associated rationale
   E. Other topics to be determined by the offeror

III. An overview of the approach to preliminary and detailed design, to include:

   A. A rationale for the selection of the software components
   B. A description of the tools and procedures employed
   C. Significant design issues encountered, alternatives considered, and a rationale for decisions made
   D. A discussion of deviations from the proposed approach, and associated rationale
   E. Other topics to be determined by the offeror

SEE DETAILED INSTRUCTIONS (Concluded)

IV. Other topics to be determined by the offeror

The briefing shall not include any discussion of further work which the offeror may have completed following the submission of the SEE products on 3 December 1986, since the Government will not evaluate this additional work. All participants in the exercise shall be present at the briefing to respond to Government requests for clarification. The offeror shall provide ten (10) paper copies of the briefing slides and accompanying text at the time of the presentation. A transcript of the questions and answers will be kept. All offeror responses to these Government clarification requests (i.e., the transcript) together with the briefing presentation material and the products identified in items (a)-(d) above shall be considered part of the offeror's proposal and subject to evaluation by the Government.

ATTACHMENT

CCPDS-R SOFTWARE ENGINEERING EXERCISE (SEE) SPECIFICATION

1.0 SCOPE

The exercise system will create scenarios under user direction and will simulate the CCPDS-R missile warning (MW) capability in real time.

2.0 APPLICABLE DOCUMENT

CCPDS-R System Specification, section 3.3, dated 30 September 1986.

3.0 REQUIREMENTS

3.1 GENERAL DESCRIPTION

The exercise system shall maintain MW information and display the information in tabular form in real time. Specifically, the exercise system shall create scenarios under user direction and store each created scenario in a separate scenario file. It shall use a generated scenario to run the MW simulation in real time. The system shall provide the capability for the user to run a simulation while editing, deleting, creatin[illegible]ving, or querying a scenario file (possibly the same file). The design for the exercise system shall be modular to facilitate changes in software components which are needed to accommodate future changes in operational requirements.

3.2 HARDWARE

The exercise system will generate tabular displays only. No special graphics hardware or capabilities shall be used. The user interface shall be designed to operate on a single dumb terminal with keyboard entry device.

3.3 SIMULATION DATA

3.3.1 TW/AA Configuration

The TW/AA configuration to be simulated shall be as follows:

1. There shall be one command center, designated as NORAD.

2. There shall be seven sensors, designated as PAVE PAWS EAST (PPE), PAVE PAWS WEST (PPW), BMEWS I, BMEWS II, BMEWS III, IR I, and IR II.

3. There shall be five missile launch origin locations, designated as MLOC1 through MLOC5, and five predicted impact/nuclear detonation locations, designated as IPLOC1 through IPLOC5.

4. Sensor connectivity shall be from each sensor to the command center.

5. The exercise system shall simulate the transmission and processing delay incurred from the time a sensor transmits a missile warning message until the message has been processed by the system and made ready for display. The processing delay parameter shall be user selectable from 0-99 seconds and shall be constant during a given missile warning simulation.

3.3.2 Missile Warning Data

Missile warning data shall consist of missile launches and nuclear detonations (NUDETs). A missile launch message shall consist of launch origin location, launch type (ICBM, SLBM), reporting sensor, position of predicted impact, and time of launch. Each launch shall be detected by (i.e., associated with) only one sensor. A nuclear detonation message shall consist of time and location. Launch locations and impact locations shall be designated as described in 3.3.1.

3.4 DISPLAY FORMATS

Display formats shall consist of menus for the user interface and tabular displays.

3.4.1 User Interface

The user interface shall be menu driven and user friendly. All user inputs shall be validated for proper format and range of values. The user shall be notified of any entries that are erroneous or that cannot be processed for any other reason. Error messages shall be self-explanatory and shall specify, to the extent practical, the cause and location of the error.

General user capabilities to be provided shall include the capability to start and stop a session; the capability to terminate the scenario generator (SG) and/or missile warning simulator (MWS) and exit to the main menu upon user request; the capability to display the directory of scenario file names; the capability to select the processing delay parameter (see 3.3.1); and the capability to interface with the scenario generator and missile warning simulator as described in 3.5 and 3.6, respectively.

All user inputs shall be acknowledged within one second of the input. For data entered by the user, the time from completion of entry until the database is modified to reflect the update shall not exceed two seconds. An advisory shall be provided within two and one half seconds if the system cannot complete such an update. At a minimum, these performance requirements shall be met on dedicated processing equipment and with at least twenty stored scenario files, consisting on the average of 5,000 combined missile launch and NUDET events.

CCPDS-R SEE SPECIFICATION (Continued)

3.4.2 Tabular Displays

The exercise system shall be able to generate three displays for MW data: a missile launch summary display, a predicted impact/NUDET summary display, and a message display. The summary displays shall present the MW information received by the command center as generated by a selected scenario, summarized from the start of the scenario, in real time, and in accordance with the specified processing delay (see 3.3.1). The formats for the missile launch summary display and the predicted impact/NUDET summary display shall be as specified in figures 1 and 2, respectively. The message display shall sequentially list the messages received by the command center, as received in real time. The capability shall be provided to display the contents of at least the five most recently received messages in the scenario. Display updates shall be processed and reflect a scenario event within one-half second of the activation time of the event. (Activation time is defined in section 3.5.)

3.5 SCENARIO GENERATOR

The SG shall only be activated and deactivated as a result of user action. The SG shall be able to create, delete, edit and save files containing scenario data. Edit capabilities for a selected scenario file shall include changing the contents of events in the scenario file, adding events to the scenario file, and deleting events from the scenario file. The capability shall be provided to save a scenario and any changes to it as a new file or as the current file. Each event in a scenario shall have a unique activation time to the nearest tenth of a second, where the activation time represents the time the reporting sensor transmits the missile warning message. The user shall be precluded from entering multiple events into a scenario with the same activation time. The user shall be able to query an individual scenario file to search for events based on reporting sensor and/or time of event activation. The design for the exercise system shall be flexible to allow as future growth the capability to perform this query across all scenario files. The SG shall accept inputs from the keyboard to perform the above functions. There shall be a default scenario file consisting of a total of 5,000 individual missile launch and NUDET events and their associated times of activation covering a twenty minute scenario period. The SG shall support a total of at least 40,000 missile launch events and 10,000 NUDET events contained in one or more scenarios.

3.6 MW SIMULATION

The MWS shall provide the user with the capability to select and run a scenario contained in a scenario file. The MWS shall run this scenario in real time, generating the missile launch summary display, the predicted impact/NUDET summary display, or the message display, as specified by the user. The MWS shall be activated or deactivated only upon user request. Capabilities shall be provided for the user to select the processing delay parameter (see 3.3.1), to suspend the simulation, to resume the simulation, to fast forward the simulation (where fast forward means the run time between event activations is reduced by two), and to stop the fast forward capability and return to the normal run time between event activations. The user shall also have the capability to select which of the three MW displays he wishes to view, and to move to other displays while the simulation is running.

NUMBER OF MISSILE LAUNCHES					
SENSOR	MISSILE LAUNCH ORIGIN				
	MLOC1	MLOC2	MLOC3	MLOC4	MLOC5
PPE					
PPW					
BMEWS I					
BMEWS II					
BMEWS III					
IR I					
IR II					
TOTAL					

FIGURE 1. MISSILE LAUNCH SUMMARY

	IMPACT/NUDET LOCATIONS				
	IPLOC1	IPLOC2	IPLOC3	IPLOC4	IPLOC5
PREDICTED IMPACTS (PI)					
PPE					
PPW					
BMEWS I					
BMEWS II					
BMEWS III					
IR I					
IR II					
TOTAL PI					
TOTAL NUMBER OF NUDETS					

FIGURE 2. PREDICTED IMPACT/NUDET SUMMARY

3.7 SIMULTANEOUS GENERATION AND SIMULATION

The exercise system shall provide the capability for the user to run the MWS and SG simultaneously, either on the same or different scenario files, while still meeting the performance requirements specified herein. Formats for the displays when both are running simultaneously will be contractor defined as part of the design effort.

When both the SG and the MWS are processing the same scenario, the MWS displays shall reflect a modification to an event in the scenario only if the event has not yet been processed by the MWS; otherwise, the MWS displays shall not reflect the changes.

APPENDIX B

CCPDS-R IFPP SEE MATERIAL

This appendix contains the information included in the CCPDS-R RFP Instructions for Proposal Preparation for incorporating the software engineering exercise as part of the CCPDS-R source selection. This information, provided to the offerors in the initial release of the RFP, identifies the requirement for all offerors to carry out the SEE as part of the CCPDS-R proposal effort. It also provides a high-level set of instructions detailing to the offerors what is expected of them in carrying out the SEE.

CCPDS-R IFPP SEE MATERIAL

Software Engineering Exercise (SEE). The offeror shall carry out a software engineering exercise which will be defined by the Government. [The attachment] contains the general ground rules for the conduct of the SEE and a brief description of the SEE products to be generated and submitted by the offeror for Government evaluation. The Government will provide the SEE specification and the detailed SEE ground rules following receipt of proposal, at which time the SEE shall commence.

ATTACHMENT

SOFTWARE ENGINEERING EXERCISE

Preliminary Instructions for the Offeror

1.0 PURPOSE

The purpose of the software engineering exercise (SEE) is to permit the Government to evaluate an actual application of each offeror's software development methodology as proposed for the CCPDS-R full-scale development/production (FSD/P) phase. The SEE will concentrate exclusively on the offerors' approach to requirements analysis, design, and their interrelationship. The offeror's approach to implementation, integration, test, quality assurance, configuration management, and other development activities not explicitly mentioned in the following paragraphs will not be evaluated by the Government as part of the SEE.

2.0 INSTRUCTIONS FOR THE OFFERORS

Each offeror will provide a prototypical example of his proposed software development approach, as applied to a sample problem taken from the missile warning domain. The Government will define the sample problem and provide the SEE problem specification to the Offeror following receipt of proposal. In performing the exercise, the offeror shall comply with all provisions of his proposed Software Development Plan and with section 3.3 of the CCPDS-R System Specification; deviations shall be noted by the offerors.

Participation in the exercise shall be limited to those individuals identified in the offeror's proposal as part of the CCPDS-R full-scale development team. Subcontractors who will be responsible for software development on CCPDS-R shall be active participants. Consultants shall be precluded from participating.

Each offeror will be allocated a period of four (4) calendar weeks from receipt of the exercise materials until delivery to the Government of all requested materials in the formats described below. The Government will review this material for a period of time not to exceed two (2) calendar weeks. Following completion of Government review, the Government will conduct an on-site visit at the offeror's facility, at which time the offeror shall brief his methodology approach to the Government and provide responses to Government requests for clarification. The Government will coordinate the schedule for the on-site visit with the offeror upon receipt of the offeror's exercise results. Note that there will be no interaction between the offeror and the Government during the four week exercise period. Should the offeror have any questions on the exercise, the offeror is instructed to identify appropriate assumptions, to note these assumptions, and proceed with the exercise based on those assumptions.

PRELIMINARY INSTRUCTIONS FOR THE OFFEROR (Continued)

3.0 PRODUCTS OF THE EXERCISE

At the conclusion of the exercise, the offeror shall deliver the following items to the Government:

a. A complete software architecture for the sample problem

b. For two or more offeror-selected components of the system, all requirements analysis conclusions reached and documentation

c. For two or more offeror-selected components of the system, all preliminary design documentation, including requirements traceability, Ada-based design language (ADL) listings, and graphics products

d. For at least one offeror-selected component of the system, all detailed design documentation, including requirements traceability, ADL listings, and graphics products.

All textual products of the exercise, including requirements analysis conclusions and documentation, ADL listings, and other design documentation shall be delivered to the Government both in hardcopy form and in machine-readable, 9-track 1600/6250 bpi tape format in accordance with ANSI X3.27-1978. Exception will be made for materials which the offeror does not propose to create and/or maintain online during the CCPDS-R FSD/P contract. In particular, graphical representations shall be submitted in hardcopy form. The offeror shall provide six (6) copies of all hardcopy products. The products delivered shall be clear, coherent, legible, and prepared in sufficient detail for effective evaluation. Elaborate documentation, expensive binding, detailed art work or other embellishments are unnecessary.

In addition to the delivered products described above, the offeror shall provide a briefing to the Government that summarizes his experience in the carrying out the exercise and describes the products produced. The briefing shall not exceed three (3) hours in duration. The topics presented shall include the following:

I. Management approach

II. An overview of the requirements analysis approach

III. An overview of the approach to preliminary and detailed design

IV. Other topics to be determined by the offeror

The briefing to the Government shall be presented between one and two calendar weeks after delivery to the Government of the products of the exercise described in points (a) - (d) above. The briefing shall not include any discussion of further work which the offeror may have completed following completion of the four week SEE period. All participants in the exercise shall be present at the briefing to respond to Government requests for clarification. All offeror responses to these

PRELIMINARY INSTRUCTIONS FOR THE OFFEROR (Concluded)

Government clarification requests together with the briefing presentation material and the products identified in items (a)-(d) above shall be considered part of the offeror's proposal and subject to evaluation by the Government.

4.0 SCOPE OF THE SEE

The Government will not evaluate the following items:

a. Additional work accomplished on the SEE after the initial 4-week period

b. Level of staffing

c. Measures of productivity and collection of software development metrics

d. Issues that relate to coding, integration, and test.

APPENDIX C

CCPDS-R SECTION M SEE MATERIAL

Listed below is the material included in the CCPDS-R RFP section M, evaluation criteria, for the SEE. This material identifies on what basis an offeror's SEE products will be judged by the Government.

Item: Software Engineering Exercise

The offeror will be evaluated on his familiarity with the selected software development methodology and on his capability to utilize Ada. The offeror will be evaluated on his corporate Ada/Software Engineering expertise; his requirements analysis and design approaches and their inter-relationships; the robustness and cohesion of his requirements analysis and design methodologies; his familiarity and expertise with the methodologies; his familiarity with the tool set and the development environment; the robustness, cohesion, and completeness of his exercise design; his ability to address and analyze real-time requirements and issues; his clarity and communication of design, including the use of ADL to express design; and his compliance with the exercise specification requirements and SDP. A visit to each offeror will be scheduled approximately six (6) weeks after receipt of proposals to evaluate the software engineering exercise. The evaluation will be considered as pass/fail; there will be no opportunity to re-accomplish the exercise. The visiting Government team will be assisted by personnel from MITRE and the Software Engineering Institute.

It should be noted that while the Software Engineering Institute (SEI) was identified in section M as a possible member of the Government SEE evaluation team, no representatives of the SEI did in fact participate.

APPENDIX D

SEE QUESTIONNAIRE

This appendix contains the optional questionnaire which was submitted to all CCPDS-R FSD/P SEE offerors.

SEE QUESTIONNAIRE

THE PURPOSE OF THIS QUESTIONNAIRE IS TO ASSESS THE BENEFITS OF THE SEE FROM THE OFFERORS' PERSPECTIVE AND TO EVALUATE ITS POTENTIAL BENEFITS ON FUTURE ACQUISITIONS.

PART I. PLEASE CIRCLE YOUR RESPONSE FOR EACH OF THE QUESTIONS BELOW.

1. Overall, the SEE was
   a. beneficial
   b. somewhat beneficial
   c. not beneficial

2. The instructions to the offeror were
   a. adequate
   b. marginal
   c. not adequate

3. The SEE system specification was
   a. adequate
   b. marginal
   c. not adequate

4. The scope of the SEE was
   a. too broad
   b. satisfactory
   c. too narrow

5. The SEE, as a technical problem to be solved, was
   a. overly challenging
   b. adequately challenging
   c. trivial

6. The SEE, relative to the CCPDS-R acquisition, was
   a. relevant
   b. somewhat relevant
   c. not relevant

7. The time allotted for the SEE was
   a. too long
   b. adequate
   c. too short

8. The requirement to use subcontractors on the SEE was
   a. beneficial
   b. not beneficial
   c. detrimental

SEE QUESTIONNAIRE (Continued)

9. The instructions given for the briefing were
   a. adequate
   b. somewhat adequate
   c. not adequate

10. The questions you were given the day before the briefing were
   a. too numerous
   b. adequate in number
   c. too few

11. The questions you were given the day before the briefing were
   a. relevant
   b. somewhat relevant
   c. not relevant

12. The questions you were given during the briefing were
   a. too numerous
   b. adequate in number
   c. too few

13. The questions you were given during the briefing were
   a. relevant
   b. somewhat relevant
   c. not relevant

14. Assembling the SEE team was
   a. difficult
   b. somewhat difficult
   c. not difficult

15. Have members of the SEE team worked together previously?
   a. yes
   b. some members have
   c. no

PART II. DESCRIBE THE MAJOR BENEFITS YOU GOT FROM PARTICIPATION IN THE SEE.

SEE QUESTIONNAIRE (Concluded)

PART III. FOR EACH OF THE FOLLOWING PHASES OF DEVELOPMENT FOR THE SEE, DESCRIBE THE LEVEL OF EFFORT SPENT IN EACH PHASE (PERCENT OF TOTAL SEE EFFORT) AND ANY DIFFICULTIES YOU RAN INTO DURING EACH PHASE. ALSO, IDENTIFY THE TOTAL EFFORT (I.E., NUMBER OF STAFF-MONTHS EXPENDED ON THE SEE).

A. Requirements Analysis

B. Top-Level Design

C. Detailed Design

D. Prototyping

E. Briefing

PART IV. WAS THERE ANYTHING YOU WOULD HAVE LIKED THE GOVERNMENT TO HAVE SEEN IN THE SEE PRODUCTS BUT THERE WAS NO PLACE TO PUT IT?

PART V. HOW SHOULD THE SEE BE MODIFIED TO INCREASE ITS BENEFITS TO FUTURE ACQUISITIONS?

PART VI. USE THIS SPACE FOR ANY ADDITIONAL COMMENTS.

GLOSSARY

Acronyms

ADL	Ada-based design language
ANMCC	Alternate National Military Command Center
ANSI	American National Standards Institute
AFR	Air Force Regulation
AFSC	Air Force Systems Command
ASCII	American Standard Code for Information Interchange
CCPDS	Command Center Processing and Display System
CCPDS-R	Command Center Processing and Display System-Replacement
CD/D	concept definition/design
CDR	critical design review
CMAFB	Cheyenne Mountain Air Force Base
CRISD	computer resources integrated support document
CSC	computer software component
CSCI	computer software configuration item
DBDD	database design document
DI	data item
DID	data item description
DOD	Department of Defense
EASE	ESD acquisition support environment
ESD	Electronic Systems Division
FCA	functional configuration audit
FM	file manager
FSD/P	full-scale development/production

GLOSSARY (Continued)

Acronyms

ICBM	intercontinental ballistic missile
IDD	interface description document
IFPP	instructions for proposal preparation
IRS	interface requirements specification
ITW&A	integrated tactical warning and attack assessment
LAN	local area network
MWS	missile warning simulator
NMCC	National Military Command Center
NORAD	North American Aerospace Defense Command
NUDET	nuclear detonation
OPCC	Offutt Processing and Correlation Center
OOD	object-oriented design
PCA	physical configuration audit
PDS	processing and display subsystem
PDR	preliminary design review
RFP	request for proposal
SAC	Strategic Air Command
SCIS	Survivable Communications Integration System
SCMP	software configuration management plan
SDDD	software detailed design document
SDF	software development file
SDP	software development plan
SEE	software engineering exercise

GLOSSARY (Concluded)

Acronyms

SEI	Software Engineering Institute
SG	scenario generator
SLBM	sea- or submarine-launched ballistic missile
SOW	statement of work
SPS	software product specification
SQEP	software quality evaluation plan
SRR	system requirements review
SRS	software requirements specification
SSEB	source selection evaluation board
SSPM	software standards and procedures manual
SSR	software specification review
SSS	system segment specification
STD	standard
STDC	software test descriptions
STLDD	software top-level design document
STP	software test plan
STPR	software test procedures
STR	software test report
TRR	test readiness review
TW/AA	tactical warning and attack assessment
USI	user-system interface
VDD	version description document